COMPRESSIBILITY AND PERMEABILITY CHARACTERISTICS OF NANO-CHEMICAL TREATED KUTTANAD SOFT-CLAY

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ABSTRACT: Expensive soils denote clayey soils that not only possess the tendency to increase or decrease in volume (compressibility) when the prevailing moisture condition is allowed to change but also measure of the ability of a soil media to support the formation of a magnetic field within itself(permeability). Such change of moisture content of these soils can emanate from rains, floods or leakage of sewer lines. The response of expensive soil in form of compressibility and permeability due to change moisture content is frequently expressed superficially as heaving, settlement and piping (flow in stream lines) of lightly loaded geotechnical structures such as pavements, railways, roadways, channel and foundations or reservoir lining. This thesis is an experimental study evaluating the effect of nano-chemical on compressibility and permeability of expansive soil. The initial phase of the experimental program includes the study of the effect of nano-chemical on MDD (Maximum Dry Density) and optimum moisture content (OMC) with different percentages (by dry weight of the soil). The second phase of the experimental program focuses on Compressibility and Permeability characteristics of the soil. In addition to UCS tests were performed to study the effects of nano-chemical on unconfined compressive strength of tested soil. Test results indicated that addition of nano-chemical reduced the compressibility and increased the permeability of the soil soil with increasing nano-chemical with respective percentages. This project ventures to find the feasibility of using a Nano chemical as stabilizer for ground improvement and to find an optimum dosage of the stabilizer which ensures maximum strength, controlling compressibility and permeability characteristics. Different dosages of Terrasil (a Nano-chemical) will be injected into the soil samples collected. The compaction and unconfined compression (UCS) tests are to be conducted, followed by consolidation and permeability test to determine the soil characteristics of controlling compressibility and permeability. It is also planned to study the suitability of the Nano-chemical as a water resistant substance for improving the strength. From the data thus obtained, an optimum dosage of the Nano-chemical to be added for maximum efficiency is determined.

Keywords: Terrasil, Nanotechnology, Nanochemicals, Soil microstructure

INTRODUCTION

The Soil stabilization is the alteration of any inherent property of a soil to improve its engineering performance. The study is aimed to improve the engineering performances of locally available in situ materials by treating it with Nano-chemicals. Nano-chemicals are nanotechnology based product which can provide solutions to prevent moisture migration and process strong bonding in treatment layers. Addition of nanoparticles to locally available soil as an external factor will result in soil manipulation at atomic or molecular level and it influences the strength, permeability indices and compressibility and permeability properties of soil.

Chemical Stabilization

Chemical stabilization is dealing with modification of the actual chemical make-up of the soil matrix. Some of these mechanisms are listed below.

Lime/Cement: Lime stabilization can be explained by three phases with the first phase being hydration of quicklime, the second phase is flocculation, which results in an immediate reduction of plasticity and the final phase of lime stabilization is the long-term cementation phase.

Mechanical Reinforcement

Mechanical reinforcement materials are mostly made of polymers and plastics, but can also be made from wood fibers, glass fibers etc. Due to their highly frictional nature, mechanical reinforcement is used as a stand-alone stabilizer which is limited to coarse-grained materials. Clay soils can be treated with mechanical reinforcement in combination with lime or cement stabilization.

New Stabilization Techniques

New techniques are to be developed that gives all-season, pothole-free roads, ensuring faster transportation to people and minimizing the risk of accidents. Nanotechnology is one among the reformed mode which when potentially can redefine and address the rising concern of poor quality roads. As per the America Chemical Society one nanometer equals one billionth of a meter. Nanotechnology is dealing with sizes in the range of 1-99 nanometers. At the micro scale, most of the properties remain almost the same as those for bulk materials.

Terrasil

Terrasil chemical is evolving as a new material for the stabilization of soil. Terrasil is nanotechnology based 100 % organo-silane, water soluble, ultraviolet and heat stable, reactive soil modifier to waterproof soil subgrade. It reacts with hydrophilic silanol groups of sand, silt, clay and aggregates to convert it to highly stable water repellent alkyl Siloxane bonds and forms a breathable in-situ membrane. It is water soluble, chemically reactive and non-leachable and works fine with all silicate containing materials. It can be applied mostly to all types of soil. Being a Nano modification terrasil keeps the pores open to allow vapor to escape while preventing water to enter in. Nanochemicals can be considered as environmental friendly since they conserve limiting resources like aggregates and bitumen. They are very economic by reducing the transportation expenses as they allow the use of in-situ soils.

MATERIALS USED

Soft Clay

The soft clay sample used for testing program was collected from Champakkulam near Kuttanad region in Kerala. The soil was taken from a depth of 2m below the ground level in already existing open pit for construction of well. Sample collected was air-dried and pulverized and the basic properties of the soil were determined and listed in Table 1.

Chemical compound	**Value in range (%)**
Hydroxyalkyl-alkoxy- alkylsilyl	65-70
Benzyl alcohol	25-27
Ethylene glycol	03-05

Table 1 Basic soil properties

Cement

Ordinary Portland cement of 43 grade was used. The brand of cement selected for the testing was RAMCO. Addition of cement causes modification of mechanical or physical characteristics of soil, such as flexural strength, resilient modulus, fatigue, shrinkage and durability. Soil plasticity and water content will be reduced.

BASIC PROPERTIES OF TERRASIL NANOCHEMICAL

Terrasil is nanotechnology based 100 % organo-silane, water soluble, ultraviolet and heat stable, reactive soil modifier to waterproof soil subgrade. It reacts with water loving silanol groups of sand, silt, clay and aggregates to convert it to highly stable water repellent alkyl Siloxane bonds and forms a breathable in-situ membrane. It resolves the critical sub-surface issues. The chemical composition of Terrasil agent is shown in Table 2

Table 2 Composition of Terrasil

Property	**Description**
Appearance	Pale yellow liquid
Solid content	68±2%
Density	1.01g/ml
Viscosity at 25ºC	20-100cps
Solubility	Forms water clear solution
Flash Point	>80ºC

Optimum Dosage of Terrasil

As per technical data provided by the Zydex Industries Pvt. Ltd the required optimum dosage of Terrasil is in the range of 0.5 - 1 kg/m^3 of soil to obtain the higher UC strength values. In present work, the Terrasil dosages are varied in the range of 0.02% to 0.15% of weight of soil in order to obtain the optimum dosage corresponding to maximum strength value. Totally seven soil combinations were prepared after adding the terrasil amounts of 0.02%, 0.03%, 0.04%, 0.05%, 0.07%, 0.10% and 0.15% into clay soil. Initially, nano-chemical solution has been prepared after adding predetermined dosage of Terrasil agent in the required optimum quantity of water. Further, the soil combinations are prepared by spraying the nano-chemical solution on loose soil and mixing uniformly. The mixture was kept air tight for curing. Mechanical properties of Terrasil nanochemical is listed in Table 3.

Table 3 Mechanical properties of Terrasil

Sl. No.	Property	Values
1	Specific Gravity	2.42
2	Consistency limits	
	Liquid limit (%)	61.91
	Plastic limit (%)	30
	Plasticity Index (%)	31.91
3	Shrinkage limit (%)	17
4	IS Soil classification	CH
5	Engineering properties	
	IS Light compaction	
	(a) MDD (g/cc)	1.48
	(b) OMC (%)	26
6	UCS (kN/m^2)	31.3
7	Co-efficient of permeability(cm/s)	4×10^{-6}
8	Consolidation	
	Compression index Cc	0.1905
	Co-efficient of compressibility av(kg/cm2)-1	0.055
	Co-efficient of volume change mv(kg/cm2)-1	0.033
	Co-efficient of consolidation Cv (cm2/min)	0.0014
9	CBR value for IS heavy compaction Unsoaked (%)	1.07

EXPERIMENTAL INVESTIGATION

CEMENT TREATED CLAY SOIL

The cement treated clay soil was prepared after mixing the 1.5% cement by dry weight of soil into the clay soil. Further, various laboratory tests like UC strength test was conducted on soil-cement mixtures to examine the effect of cement on improvement of geotechnical properties of clay soil.

Unconfined compressive strength

To find the compressive strength values of each cemented treated clay soil mixture, various UCS tests were performed on samples prepared at its maximum dry density by controlling the optimum water content. The samples were tested for different curing periods 1, 7, 14 and 28 days in order to examine the effect of curing on compressive strength properties.

Table 4 UC Strength of cement treated clay soils at different curing times

cement dosage %	UC Strength, kPa			
	1 day of curing	7 days of curing	14 days of curing	28 days of curing
1.5	35.6	38	42	44.1

For each cemented treated clay soil mixture, three similar UCS specimens were prepared and tested to obtain the average value of UC strength. The stress-strain curve for soil-cement mixture is obtained after conducting the UCS test at end of the 28 days curing period. It shows the UCS value increasing with time and UCS was increase from 31.3 to 44.1kPa. The increased strength at 28 days of curing is about 1.4 times the strength of untreated soil.

NANOCHEMICAL TREATED CLAY SOIL

SOIL - TERRASIL – CEMENT MIXTURES

Seven combinations of soil-Terrasil-cement mixtures were prepared by adding cement proportion of 1.5% by its dry weight of soil. The Terrasil is considered as the base additive. Here, the seven combinations of Nanochemical treated clay soil samples were prepared after adding the Terrasil amounts of 0.02%, 0.03%, 0.04%, 0.05%, 0.07%, 0.1% and 0.15% in to the clay soil. Nano-chemical solution has been prepared after adding predetermined dosage of Terrasil agent in the required optimum quantity of water. Further, the soil combinations are prepared by spraying the nano-chemical solution on loose soil and mixed uniformly. The Terrasil treated samples were tested for consistency limits, UCS properties. The samples were tested for consistency limits, compressive strength at different curing times in order to examine the effect of curing on strength properties.

Consistency Limits

The obtained results are tabulated in Table 4.2. Terrasil is introduced into the clay soil from 0.02 to 0.07% weight of soil. The plasticity index reduced from 31.91% (untreated) to 22.24% (for optimum terrasil at the end of 28 days of curing). It indicates that the soil become less plastic state with the addition of optimum level of 0.03% nano-chemical into the clay soil.

Table 5 Consistency limits of nano-chemical treated clay soil at different curing periods

Terrasil dosage %	Plasticity Index PI (%)		
	7 days of curing	14 days of curing	28 days of curing
0.02	25	23	23.2
0.03	24	22.76	22.24
0.04	25	23.6	22.8
0.05	25.8	24	23.4
0.07	27.9	24.88	24

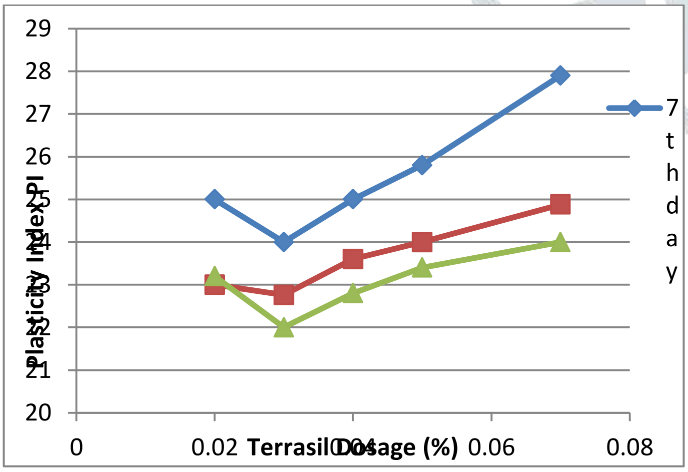

Fig.1 Consistency limits of nano-chemical treated clay soil at different curing periods

Unconfined Compression Strength

To find the compressive strength values of each chemical treated clay soil mixture, various UCS tests were performed on samples prepared at its maximum dry density (1.48 g/cc) by controlling the optimum water content (26%). The samples were tested for different curing periods 1, 7, 14 and 28 days in order to examine the effect of curing on strength properties. For each chemical treated clay soil mixture, three similar UCS specimens were prepared and tested to obtain the average value of UC strength.

Table 6 UC Strength of Terrasil treated clay soils at different curing periods

Terrasil dosage %	UC Strength, kPa			
	1 day of curing	7 days of curing	14 days of curing	28 days of curing
0.02	48	50.1	54	64
0.03	54.6	58.1	65.9	75.7
0.04	50	52	61.8	68
0.05	47.3	48.6	56.7	61.2
0.07	45.8	47.9	52.1	57.6
0.1	43.5	47	51.7	55.2
0.15	39.8	46.6	50.9	52.1

The effect of Terrasil dosage and curing time on UC strength of clay soil is illustrated in Table. Irrespective of all dosages, the increased strength at 28 days of curing is about 1.3 to1.4 times the strength at 1 day of curing. The UC strength is more in the case of soil mixed with 0.03% Terrasil chemical irrespective of all curing times. It indicates the optimum dosage of Terrasil chemical added to the soil is 0.03% which one leads to maximum UC strength.

SOIL-0.03% TERRASIL -CEMENT MIXTURES

Seven combinations of soil-Terrasil-cement mixtures were prepared by adding cement proportion of 1.5% by its dry weight of soil. The Terrasil is considered as the base additive. The dosage of Terrasil is fixed at an optimum value of 0.03% which was obtained after testing on soil-Terrasil mixtures. Then the experimental tests were conducted on soil-cement-Terrasil mixtures to examine the combined effect of Terrasil and cement on improvement of permeability, consolidation characteristics and CBR strength properties of clay soil.

Permeability

Each chemically treated test sample was compacted in the permeameter mould at a density of 1.48 g/cc after adding the optimum moisture content of 26% to the soil. The sample was drained at both end faces of mould to saturate the sample. The test results are indicating that as the dosage of nanochemical increases there is a drastic decrease in permeability. The chemical reaction leads to permanent siliconization of the surfaces and this made the soil waterproof. The test results show that the permeability of all chemical treated soils is almost insignificant.

Table 7 permeability test results for untreated and treated soils

Terrasil dosage %	Coefficient of Permeability (cm/sec)				
	untreated clay	1 day of curing	7 days of curing	14 days of curing	28 days of curing
0.03	4 × 10-6	Nil	Nil	Nil	Nil

Consolidation

The samples were prepared after adding the Terrasil chemical in the optimum dosage of 0.03% in to the clay soil. The chemical treated samples were compacted at maximum dry density after mixing the chemical with optimum water content of 26%. The tests were conducted on nanochemical treated clay samples on a two way drainage basis. The samples were also tested at different curing times of 3 days and 10 days in order to examine the effect of curing on consolidation characteristics. The following tables and graphs show the consolidation test results.

Table 8 consolidation characteristics for the soil mixed with 0.03% terrasil and 1.5% cement after 3 days curing period

S. No	Properties	Values
1	Change in void ratio, Δe	0.1293
2	Change in pressure, Δσ (kg/cm^2)	7.5
3	Settlement ,ΔH or Sf (mm)	0.82
4	Co-efficient of consolidation, Cv (cm^2/min)	0.0322
5	Co-efficient of compressibility, av (cm^2/kg)	0.0267
6	Co-efficient of volume change, mv(cm^2/kg)	0.0163
7	Compression index, Cc	0.0587

Table 9 consolidation characteristics for the soil mixed with 0.03% terrasil and 1.5% cement after 10 days curing period

S. No	Properties	Values
1	Change in void ratio, Δe	0.1693
2	Change in pressure, Δσ (kg/cm^2)	7.5
3	Settlement ,ΔH or Sf (mm)	1.171
4	Co-efficient of consolidation, Cv (cm^2/min)	0.0279
5	Co-efficient of compressibility, av (cm^2/kg)	0.0293
6	Co-efficient of volume change, mv(cm^2/kg)	0.0179
7	Compression index, Cc	0.1406

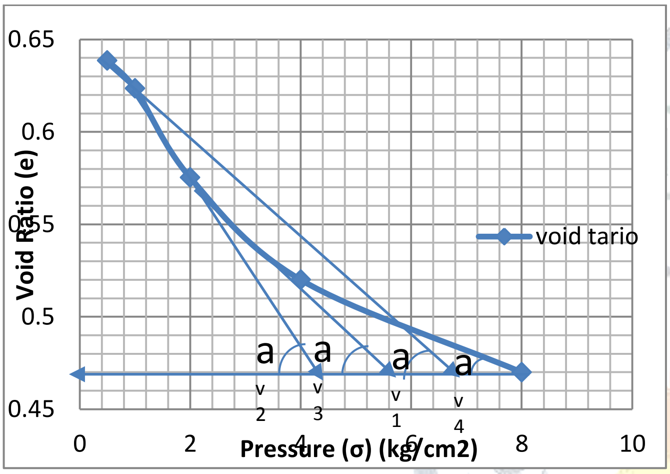

Fig.2 e- σ (void-pressure) relationship for the soil mixed with 0.03% terrasil and 1.5% cement after 3 days curing period

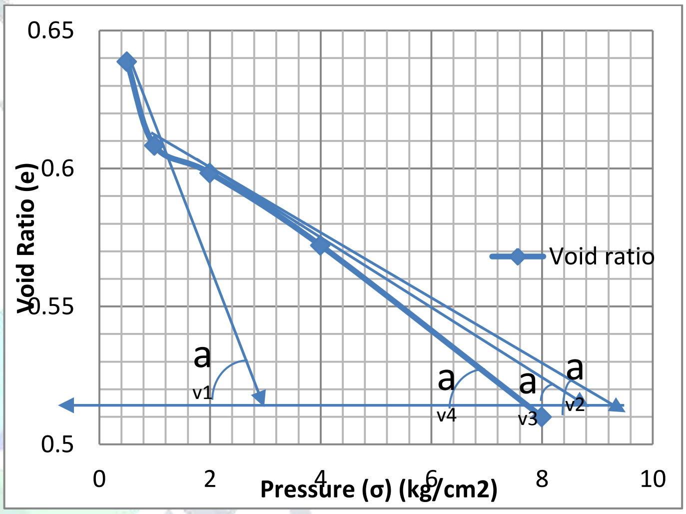

Fig.4 e- σ (void-pressure) relationship for the soil mixed with 0.03% terrasil and 1.5% cement after 10 days curing period

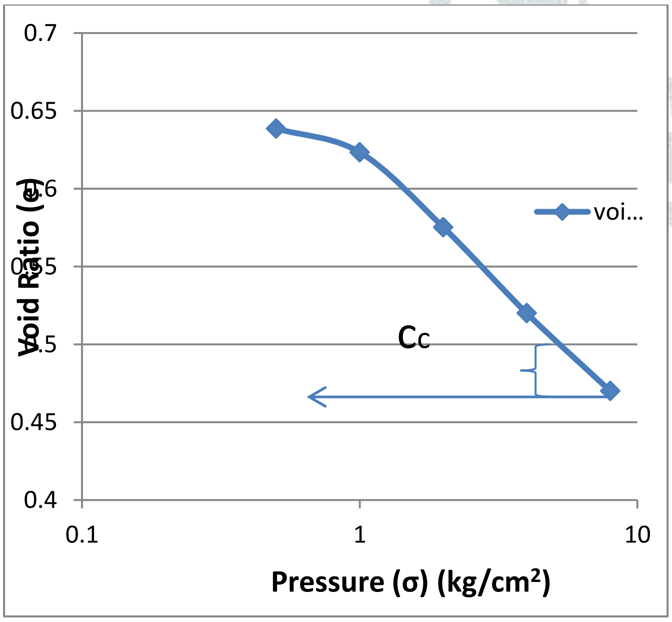

Fig.3 e- log(σ) (void-log(pressure)) relationship for the soil mixed with 0.03% terrasil and 1.5% cement after 3 days curing period

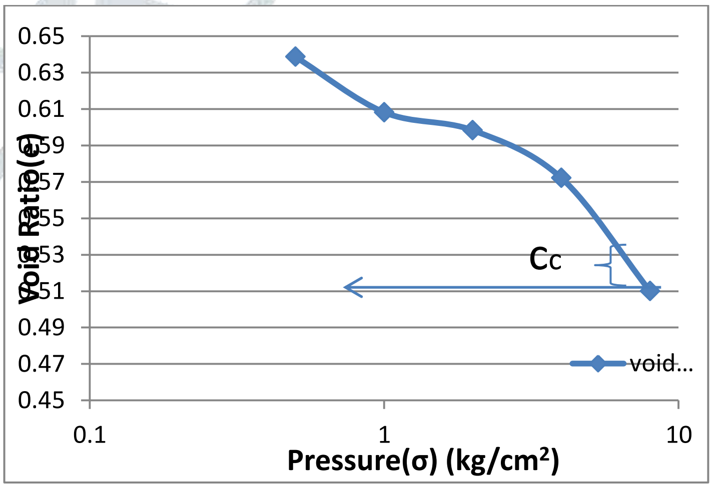

Fig.5 e- log(σ) (void-log(pressure)) relationship for the soil mixed with 0.03% terrasil and 1.5% cement after 10 days curing period

From the tests, it is observed that the coefficient of consolidation is increasing (from 0.0014 to 0.0322 cm^2/min) with respect to increasing nanochemical content and curing period, thus the soil settlement has reduced(from 3.345 to 0.82 mm) significantly for nanochemical treated soil while compared to untreated soil sample.

California Bearing Ratio

The optimum combination of sample was prepared after adding the Terrasil chemical in the optimum dosage of 0.03% in to the clay soil. The CBR chemical treated samples were compacted at maximum dry density after mixing the chemical with optimum water content of 26%. The samples were compacted by using heavy compaction hammer. The tests were conducted on unsoaked chemical treated clay samples. The samples were tested at the different curing times of 7 days, 14 days and 28 days in order to examine the effect of curing on CBR value.

Table10. CBR Strength of Terrasil treated clay soils at different curing times

Terrasil dosage %	CBR (%)		
	7 days of curing	14 days of curing	28 days of curing
0.03	1.8	2.2	3

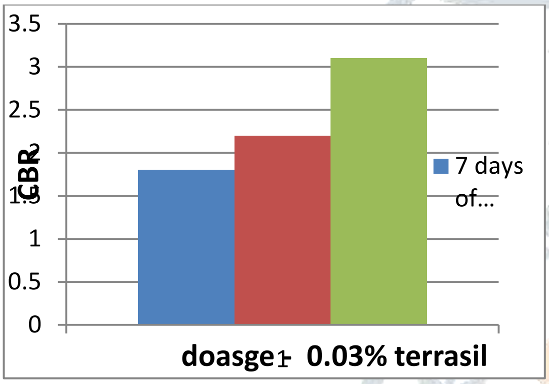

Fig.6 Effect of chemical dosage on CBR Strength at different curing times

The effect of Terrasil chemical dosages on CBR values of soil at different curing times is illustrated. It is clearly noted that the strength values are maximum at 28 days of curing. The maximum strength was reported to 3% corresponding to optimum dosage of Terrasil chemical added to the soil. Quantitatively, the strength of chemical treated clay soil is improved about 3 times the CBR values of clay soil. This improvement may be possible due to the reaction of the chemical with the soil particles and as a result it water proofs the surfaces permanently.

SEM ANALYSIS

The scanning electron microscopy was used to analyze the morphology of the untreated and stabilized soil samples. SEM micrograph of the untreated clay soil is shown in Figure 6. SEM micrographs of the stabilized soils are shown in Figures 7, 8 and 9. From images it can be understood that untreated soil sample contains more void space when compared to that of cement and terrasil treated soil samples. In the stabilized soil, particles are bound together and is seen that particles are more closely packed in terrasil treated soil samples than in the cement treated ones

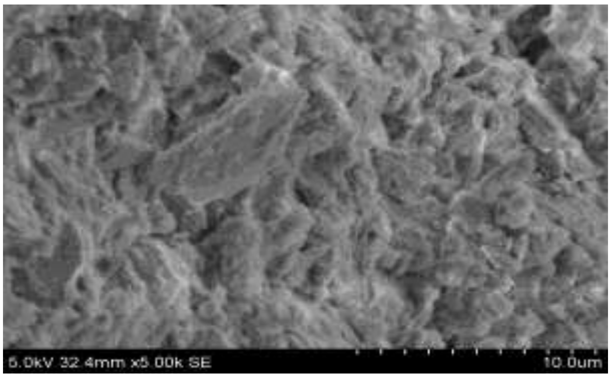

Fig.7 SEM micrograph of untreated clay soil surfaces

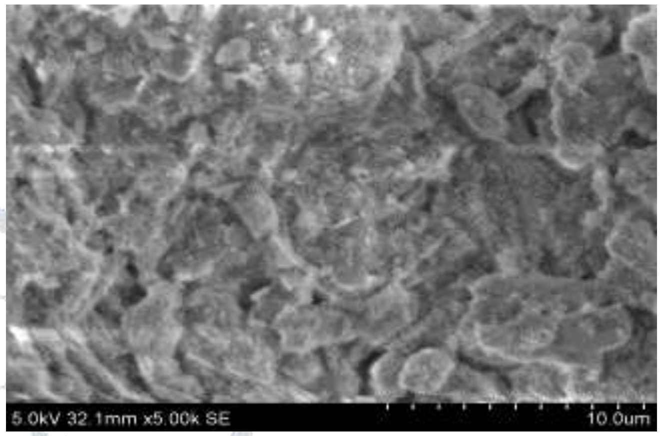

Fig.8 SEM micrograph of soil mixed with 1.5% cement

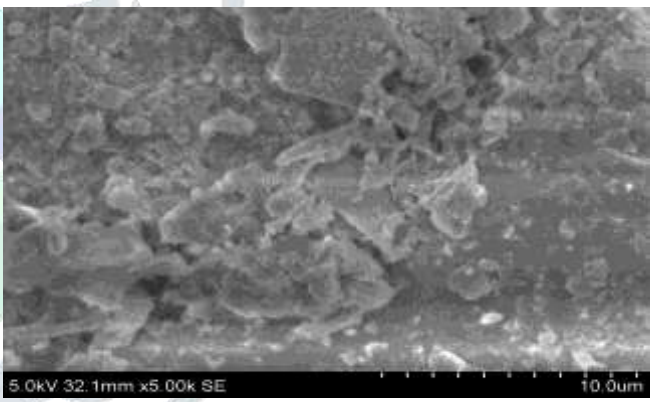

Fig.9 SEM micrograph of soil-cement mixed with 0.05% Terrasil

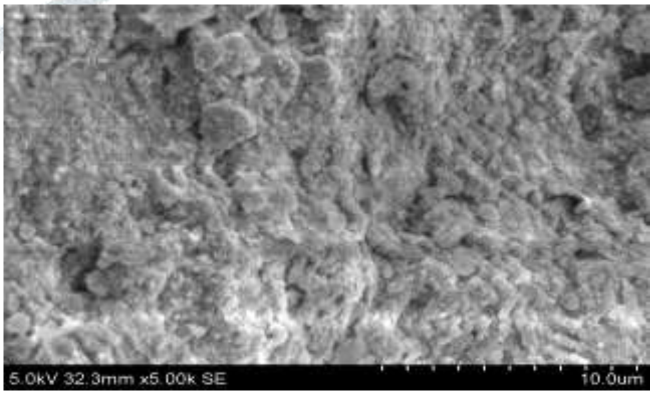

Fig.10 SEM micrograph of soil- cement mixed with 0.03% Terrasil

CONCLUSIONS

Based on discussion of experimental test results, a few of major conclusions can be listed with regards to the effect of cement and Terrasil additives on consistency limits, compaction, UCS, permeability, consolidation and CBR strength of soft clay soil.

- The soil is classified as highly compressible clay (CH) as the plasticity index of untreated soil is 31.91%, compaction characteristics like maximum dry density and optimum moisture content are 1.48 g/cc and 26% respectively and unconfined compressive strength as 0.313 kg/cm^2

- The coefficient of permeability is about 4× 10^{-6} cm/sec and the unsoaked CBR of clay soil was found to 1.07%. The coefficient of consolidation was found to 0.0014cm^2/min and final consolidation settlement is about 3.354 mm. so it is clear that the soil is highly compressible clay.

- Terrasil is introduced into the clay soil from 0.02 to 0.07% weight of soil. The plasticity index reduced from 31.91% (untreated) to 22.24% (for optimum terrasil at the end of 28 days of curing). It indicates that the soil become less plastic state with the addition of optimum level of 0.03% nanochemical into the clay soil. So it is clear that the chemical makes the soil stiff.

- Terrasil is added into the clay soil from 0.02 to 0.15% weight of soil. The unconfined compressive strength of soil increased from 31.3 kpa (untreated soil) to 75.7 kpa (for optimum terrasil at the end of 28 days of curing). The UC strength of soil mixed with optimum dosage of 0.03% terrasil chemical is improved about 2.5% higher than the strength of clay soil. This improvement is due to the reaction of the chemical with the soil particles and as a result it restricts water entering the surface.

- The soil is found impermeable at optimum dosage of terrasil for every curing period.

- The coefficient of consolidation is increasing (from 0.0014 to 0.0322cm^2/min) with respect to increasing nanochemical content and curing period, thus the soil settlement has reduced (from 3.345 to 0.82 mm) significantly for nanochemical treated soil while compared to untreated soil sample.

- The CBR value of soil mixed with optimum dosage of 0.03% terrasil nanochemical is improved about 3 times the CBR value of clay soil.

- The SEM analysis shows that particles are more closely packed for nanochemical treated soil while compared to untreated soil.

In conclusion, the soil-1.5% cement mixture added with 0.03% terrasil is the best soil combination which is exhibiting the higher UC strength, less permeable value, least settlement and high CBR values. The stabilized soil-cement-terrasil mixture is very useful as an embankment material, unlined canals, structural backfill, and other compacted fills. Also the mixture is very useful as a subgrade material.

REFERENCES:

Karumanchi Meeravali **Dr. Kodi Rangaswamy**

[1] Nader Abbasi A, Hassan Rahimi B, Akbar A, Javadi C & Ali Fakher (2007), "Finite difference approach for consolidation with variable compressibility and permeability", J Geotech Eng ASCE, 119 (9) (1993), pp. 1333–1359.

[2] B. A. Mir and A. Sridharan (2014), "Volume change behavior of clayey soil–fly ash mixtures", B. A. Mir, A. Sridharan, Pages 72-83.

[3] Cholachat Rujikiatkamjorn, Buddhima Indraratna and M. Sakr, "Laboratory Modeling of Consolidation Behavior of Soft Clays Using Vacuum-Surcharge Consolidation Method" , 25-2-2008.

[4] Masoud Janbaz, Ali Maher (2016), "Consolidation Characteristics of Soft Clays"

[5] Pragyan Bhattarai, A.V.A Bharat Kumar, K. Santosh, T. C. Manikanta & K. Tejeswini (2013), "Engineering behavior of soil reinforced with waste plastic strips", International Journal of Civil, Structural, Environmental and Infrastructure Engineering Research and Development (IJCSEIERD) ISSN 2249-6866, Vol. 3, Issue 2, Jun 2013, Pages .83-88.

[6] R. M Jones, E. J Murray (1995) "Selection of clays for use as landfill liner" , Waste disposal and landfill.

[7] Duncan, J.M., Chang, C.Y. 1970., "Nonlinear analysis of stress and strain in soils", J. Soil Mech. Found. Div., ASCE, 96(SM5),1629-1653.

[8] Zydex Industries Ltd. , www.zydexindustries.com (accessed on 10.08.2014)

[9] Ajay Ishwarlal Ranka: *Sustainability through Innovation*, Smart Construction, pp.25-27, May 2014

[10] Y S S Gopala Krishna**,** Smt. M Padmavathi and K Shiva Prashanth Kumar, *Stabilization of Black Cotton Soil Treated with Fly ash and Zycosoil*, International Journal of Civil Engineering and Building Materials (ISSN 2223-487X) Vol. 3 No.3 2013

[11] Zaid Hameed Majeed and Mohd Raihan Taha, *A Review of Stabilization of Soils by using Nanomaterials*, Australian Journal of Basic and Applied Sciences, 7(2): 576-581, 2013

[12] Chandra, S. *Stabilization of Clayey Soils With Lime, Cement and Chemical Additives Mixing*, International Symposium on Prediction and Performance in Geotechnical Engineering, pp.177-181.