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EFFECT OF COMPACTION CHARACTERISTICS AND SHEAR STRENGTH PARAMETERS OF EXPANSIVE SOIL REINFORCED WITH NANOMODIFIED COIR FIBRE AND LIME

Sindhu A.R[1], Justin K Joseph[2]

[1]*Assistant Professor, Dept. of Civil Engineering, Saintgits College of Engineering, Kerala, India*
[2]*P.G.Student, Dept of Civil Engineering, Kerala, India*

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Abstract - *Geotechnical Engineers play a vital role for development of any Country.As they design the foundations for any structures based on given soil conditions. But construction of structures on an expansive soil has been a difficult task for these engineers as these soil have low shear strength and they exhibit high volumetric changes. In order to construct structures on such soil condition, reinforcing soil has emerged to be a promising solution. Use of natural fibre has a great significance in todays scenario as environmental sustainability gains more importance in construction and hence natural fibre can be used as reinforcing agent. This helps in reducing settlement but as these fibres degrade fastly they could be used only for short term related problems. In this study an attempt has made to improve the durability of coir fibres through nanomodification via chemical treatment and then added to soil along with lime. In order to evaluate the effect of soil modification various tests like Standard proctor compaction test, triaxial tests etc were performed. The test results showed that the nanomodification of fibres helped to increase the dry density of fibres. Also it was observed that the shear strength parameters of the soil increases with fibre content. It was also found that with the increase of time the cohesion and angle of internal friction increase. An extensive laboratory investigation was conducted on non-reinforced and reinforced soil. The results showed that the load bearing capacity of reinforced soil was found to be higher than the non reinforced soil. The results were compared analytically using Plaxis 3D.*

***Key Words*: Expansive soil, Nano-modification, Coir fibres, Plaxis 3D**

1.INTRODUCTION

India is a country with varying terrain, soil, climate and environmental conditions and about 33% of the total land area in India is expansive soils which are classified as weak soils. As these soil have very low shear strength they exhibit high volumetric change during wetting and drying. With rapid growing population there is a reduction of land resources. And the difficulty encountered by geotechnical engineers in constructing the structures on these soils as such soil may cause differential settlement and uplift as they swell .Foundation plays a crucial role for any structure as they have to carry the load from the superstructure and transfer it to the ground. If the soil surrounding the foundation is not strong it may cause severe damage to footing affecting the entire structure. When structures have to be constructed on such challenging ground conditions, soil reinforcement is an adaptable technique to improve ground. . This method can guarantee a greater development potential for the country and hence bring numerous benefits to the nation. In todays scenario environmental sustainability gains more importance in construction and hence eco-friendly natural material like coir fibre can be used for soil reinforcement. The reinforcement in soil improves its bearing capacity and reduces settlement .It also takes a main part in reducing the liquefaction behaviour of soil.

1.1. COIR FIBRE

Coir fibre is a biodegradable fibrous material obtained as an agro-waste from coconut plantations. The production of coir fibres from the husk of coconut is the largest in India.[4] It is estimated that around 13000 millions of nuts are harvested annually .However only 25% of this are used for industrial purpose as they are easily degradable. This destruction of potentially useful material is due to lack of alternate uses of coir fibres. Nowadays, civil engineers around the world are in constant search of alternate materials which are required for cost effective solutions particularly in developing nations. Many researchers have shown that coir fibre reinforcement can significantly improve the engineering properties of soil. But the presence of the pectins, lignin, hemicellulose, silica and pith on the surface of these fibres results in poor interaction with the soil.

2.0. LITERATURE REVIEW

Vivi Angrainni et.al ;(2016)[1] studied the reinforcing benefits of treated coir fibre and lime on the engineering properties of marine clay. Results from the experimental investigation showed that the lime and treated fibers improved the shear strength and durability of natural coir fiber. Moreover, an increase in the effective stress internal friction angle and the cohesion intercept were observed.

N.Farzadnia, H.Jahangirian et.al;(2016) [2], studied the effect of treated coir fibre on the tensile strength of the soil and its interaction with the soil. Various tests were performed like unconfined compressive strength tests, indirect tensile strength tests, flexural strength tests and triaxial compressive strength test. The results showed that treated fibres enhanced the mechanical properties of the lime-treated clay soil due to the tensile strength of the augmented fibres. The results showed that the compressive strength increased by 64%, wheareas the indirect tensile strength by 122% and the flexural strength by 56% of samples treated with modified coir respectively compared to that of samples treated with unmodified fibres.

Vishwas N.Khatri, Rakesh K.Dutta et.al;(2015)[3] studied the effect of treated coir fibres on the shear strength behavior of clay. The results indicated that the deviator stress at failure of the clay could be increased by adding treated coir fibre in clay. A significant increase was also observed in shear strength parameters of clay reinforced with coir fibres at different percentages. The clay reinforced with untreated/treated coir fibres has shown improved strength behavior, it can be used for short term stability problems.

Md Asaduzzaman, Muhammad Iftial Islam et.al;(2014)**Error! Reference source not found.** suggested a soil improvement method by using bamboo in medium dense soil. The bamboo was placed as reinforcing agent at various depths below the footing. Three various square footings were used. The bamboo used in their study was 12inch in length and 0.5inch in diameter. The results showed that bearing capacity of sand increased to 1.77 times to that of non -reinforced soil for single layer. However for multiple layers it increased up to 2.02 times. The bearing capacity increases with increase of reinforcing layer.

Above studies showed that by improving the durability of coir fibres it can be used effectively as a reinforcing material but a practical application of the same has not been done. In this study coir fibre is used as a reinforcing material beneath the foundation and its load bearing capacity and settlement characteristics were studied for both reinforced and unreinforced soil and sample were validated analytically using plaxis 3D.

3.0. Materials Used and Methods

3.1 Soil Sample

Soil samples used in the study were collected from Kaduthuruthy, Ernakulam district, Kerala. The soil sample was classified as Clayey soil with High Plasticity as per IS 1498-1970. The basic properties of the soil are listed below in table 1.

Table -1: Physical and Engineering properties of soil

Sl. No.	Description	Value
1	Colour	Grey
2	Field Moisture Content	106%
3	Grain Size Distribution	
	Clay	78 (%)
	Silt	14 (%)
	Sand	8 (%)
4	Atterberg Limits	
	Plasticity Index	85 (%)
	Plastic limit	37 (%)
	Liquid limit	122 (%)
5	Specific Gravity	2.38
6	Compaction Characteristics	
	Maximum Dry Density	1.27 g/cc
	Optimum Moisture Content	34 %
7	Shear Strength Parameters	
	Cohesion (C)	0.413 kg/cm^2
	Angle of Internal Friction(φ)	7°

3.2. Coir Fibre

Coir fibre used for the study was collected from Coir factory Alapuzha, Kerala. The fibres were 10-20mm long with a diameter of 0.1mm–0.3mm.The chemical and physical properties of the fibre were provided by factory is shown in table 2.

Table -2: Chemical and Physical properties of coir fibre

Basic Properties	Value
Chemical Properties	
Lignin	45.74%
Cellulose	43.54
Pectin's and related compound	4.00%
Water soluble	4.25%
Ash	2.22%
Physical Properties	
Unit Weight	$13 kN/m^3$
Breaking Elongation	30%
Tensile Strength	50-70MPa

3.3.Lime

Commercially available quick lime with CaO of 95% was used for the study. Lime was obtained from R.K.Traders Pvt.Ltd. Kerala, India .The loss on ignition was less than 10%.

3.4. Ferric Chloride and Sodium Hydroxide

Ferric chloride and sodium hydroxide were purchased from Science House Pvt.Ltd, Changanaserry, Kerala. Table 3 shows the Chemical composition and composition of chemicals used for the study.

Table -3: Chemical Composition of chemicals

Ferric Chloride	
Assay	96% min
Ferrous Chloride	2% max
Sodium Hydroxide	
Assay	97% min
Carbonate	2% max
Chloride	0.01% max
Sulphate	0.05%max
Lead	0.001% max
Pottasium	0.1% max
Silicate	0.05% max
Zinc	0.02% max
Iron	0.001% max

4. Experimental Procedure For Nanomodification of coir fibre

The modification of coir fibres is done by precipitation method. This method was adopted from [1].In this process ,Initially 50gm coir fibres are dipped in 500 ml aqueous solution of 0.5M $FeCl_3$ for 24 hrs to fill the pores of the of fibres by $FeCl_3$ solution. Thereafter the soaked fibres are separated from $FeCl_3$ solution and incubated/placed in another beaker having 500ml of sodium hydroxide, 0.5M and kept for 24 hrs. During this time $Fe(OH)_3$ quickly precipitates as nanoparticles on surface of fibres and in pores .Finally the fibres are removed from the solution and were washed by distilled water to remove the undesired residue such as NaCl and NaOH. Fibres were then dried at ambient room temperature.

$$FeCl_3 + 3NaOH \longrightarrow Fe(OH)_3 + 3\,NaCl \quad (1)$$

Fig.1. Untreated coir fibre

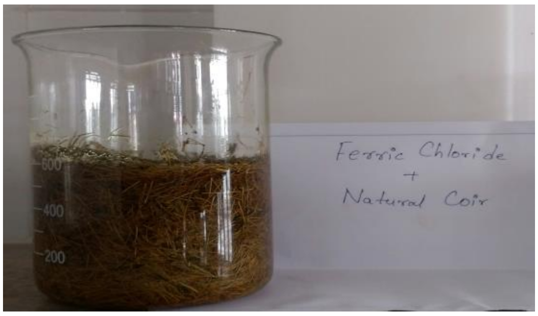

Fig.2.Coir fibre dipped in ferric chloride solution

Fig.3.Coir fibre dipped in Sodium hydroxide solution

Fig.4. Nanomodified coir fibre

4.1. Test Program

The study was to establish the effect of nanomodified coir fibre on the compaction and shear strength characteristics of the lime treated clayey soil and to reduce the settlement behaviour of clayey soil. Initially the soil was tested for compaction characteristics with addition of lime to the soil. The varying percentages of lime that were added to the soil are 2%,4%,6%,8%,and 10%.This was done to find the optimum percentage of lime that has to be added to soil and thereafter keeping lime constant and varying percentage of fibre i.e; 0.25%,0.5%,0.75%,1% and 1.25%. To study the effect of reinforcing fibres on the compaction characteristics, standard Proctor compaction test was conducted as per IS standards.

For shear strength characteristics triaxial test were done for two sets of specimens. One set of specimen which were reinforced with fibres were tested at zero days however the other set of specimens were wrapped with a thin plastic film and aluminum foil and were kept for curing and were tested after 14 days. This was done to study the effect of curing on the strength behaviour of reinforced soil. Triaxial test were Performed as per IS :2720 (Part 11) - 1971.

A model study on square footing was done in both reinforced soil and load settlement characteristics were determined. The same were analyzed numerically through Plaxis 3D.

5. RESULTS

5.1.SEM and EDX

SEM and EDX test were performed at AIMS Kochi to conform the morphology of alteration of fibres. Figure 5 shows the SEM image for an untreated coir fibre whereas figure 6 shows the SEM for treated coir fibre. In first figure there are empty lumens in fibre. In second figure this lumens are filled with ferric chloride solution also it is seen that there are few clusters of crystals of spherical shape sizing from 100 to 139nm. This crystals changes the surface of coir into a rougher one thereby through contributing to higher interaction between coir surface and soil. In untreated coir fibre there were no peaks observed for Fe (Figure 7).However in treated coir fibre the lumens of coir were filled with ferric chloride solution which were conformed through the EDX results in which there were eminent peaks of Fe observed (Figure 8).

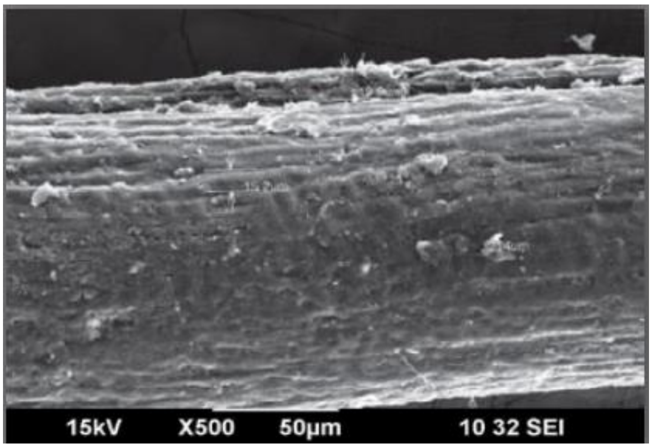

Fig.5. SEM image for untreated coir fibre

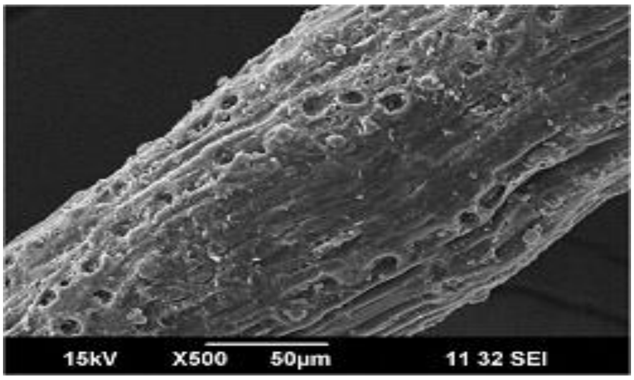

Fig.6. SEM image for treated coir fibre

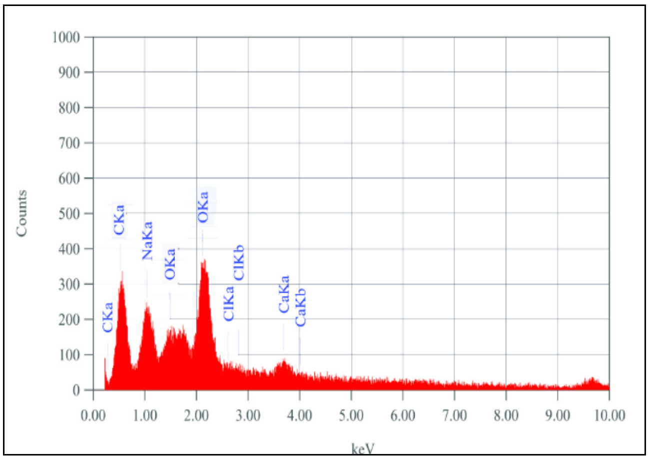

Fig.7. EDX image for untreated coir fibre

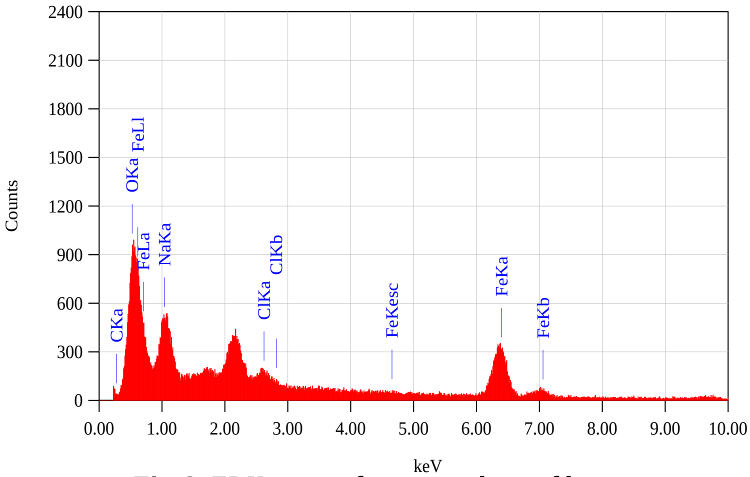

Fig.8. EDX image for treated coir fibre

5.2. Maximum Dry density and Optimum Moisture content relationship with the addition of lime in soil

For 2% lime addition to the soil the dry density of the soil decreases however which with the further addition of lime the dry density increases. The increase in the dry density becomes nearly marginable after 6% lime addition. [5]The initial decrease in dry density is because the electrolyte concentration of the pore water increases as lime content increases. As a result the thickness of the double layer gets reduced. The clay particles tends to move closer and Vander wall forces of attraction becomes predominant producing flocculation and a card type structure is formed. This structure of clay matrix resists the compaction effort, giving rise to lower density and higher moisture content.

As the lime content increases the concentration of cations increases to negatively charged surface. This difference of concentration leads to osmosis. The ions on clay surface are influence of charge they are restrained against diffusion. The water molecule diffuse towards clay surface to equalize charge concentration .Thus clay particles are separated which produces more dispersed soil structure, which allow clay particles to slide over each other into oriented and denser matrix. Here 6% of lime is taken as optimum.

Table -4. Values for MDD and OMC with addition of lime in varying percentage

SL.NO	LIME (%)	MAXIMUM DRY DENSITY (g/cc)	OPTIMUM MOISTURE CONTENT (%)
1	2	1.243	38
2	4	1.281	31
3	6	1.300	30.8
4	8	1.304	29.1
5	10	1.307	28.3

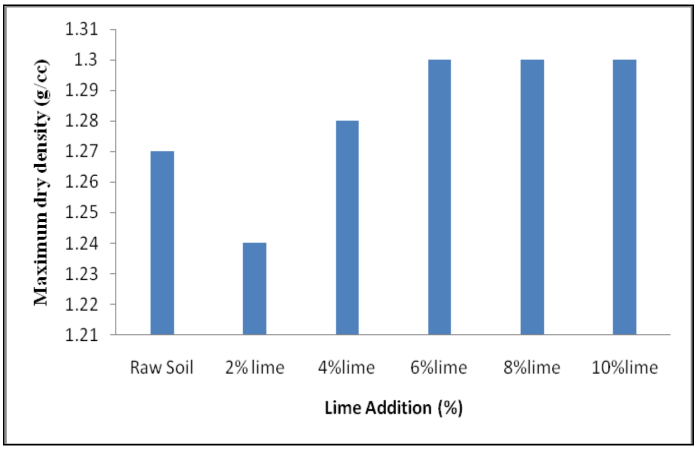

Chart -1: Variation of dry density with addition of lime

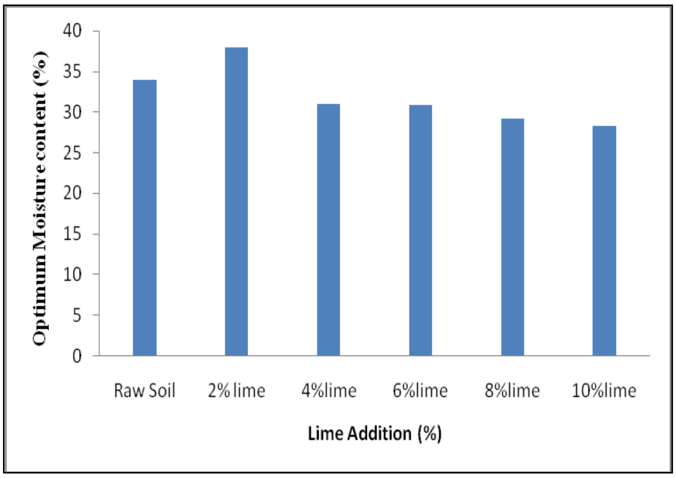

Chart -2:Variation of moisture content with addition of lime.

5.3. Maximum Dry density and Optimum Moisture content relationship with the addition of treated fibres along with lime in soil

For the untreated soil MDD value obtained were 1.27g/cc. However with the addition of treated fibres there was increase in dry density upto 0.75% of fibre addition and then decreases subsequently with further addition of fibre content. The increase in dry density may be due to better interaction of clay with fibre. The decrease in moisture content is attributed to the fact that clay specimen reinforced with $FeCl_3$ and NaOH decreases the tendency of coir fibre to absorb water .

Table -5 Values for MDD and OMC with addition of fibre and lime in varying percentage

SL.NO	LIME (%)	FIBRE ADDITION	MDD (g/cc)	OMC (%)
1	6	0.25%	1.30	33.80
2	6	0.5%	1.34	31.33
3	6	0.75%	1.39	27.66
4	6	1%	1.36	28.38
5	6	1.25%	1.35	28.77

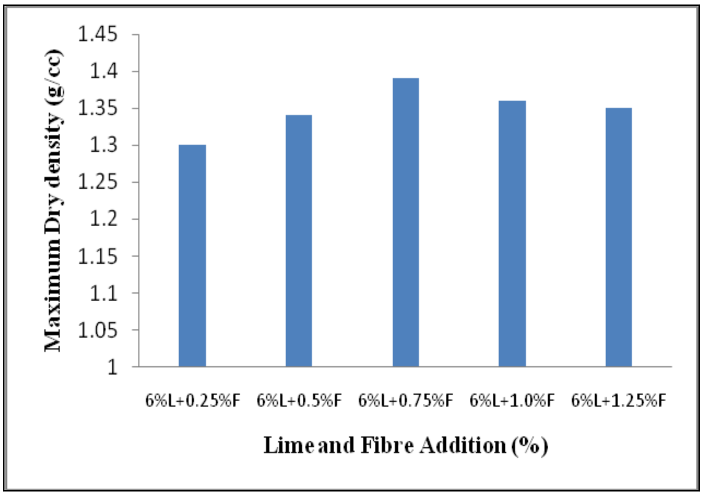

Chart -3: Variation of dry density with addition of lime and fibre

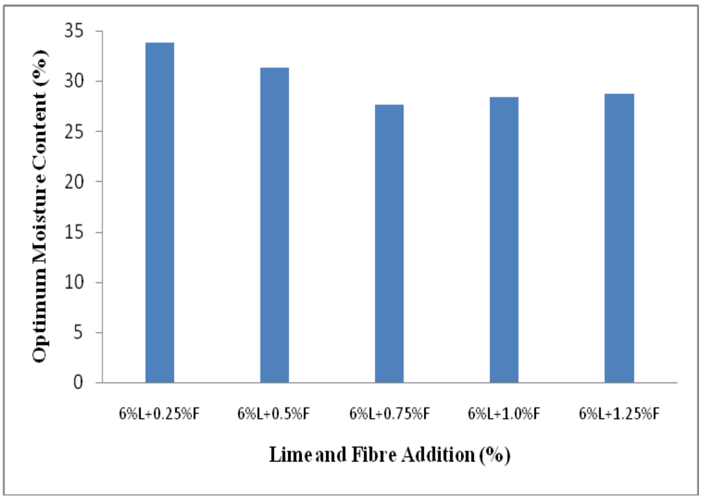

Chart -4: Variation of moisture content with addition of lime and fibre

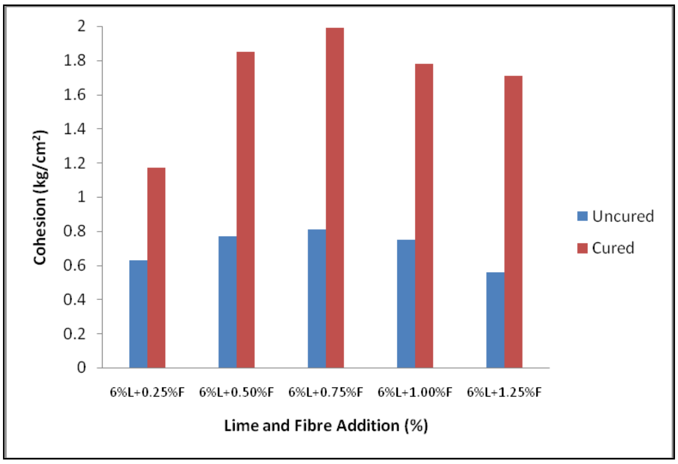

Chart -5: Variation of cohesion with addition of lime and fibre

5.4. Triaxial Compression Strength Test

In order to study the effect of fibres on shear strength parameters of the soil a number of unconsolidated undrained (UU) triaxial tests were performed as per IS : 2720 (Part 11) -1971. The triaxial tests were performed at confining pressure of 0.5,1 and 1.5 bar. The specimens were 100mm in dia and 780mm in length. Axial load was applied under controlled conditions. From the test result it was found that the cohesion and angle of internal friction increases with increase of fibre content.

In order to study the curing effect of fibres and lime the soil specimen was cured and tested after two weeks. It was found that with the increase of curing time the shear strength parameters increases.

Table -6 Values for Cohesion and angle of internal friction without and with curing

SL. NO	LIME + FIBRE ADDITION	COHESION (kg/cm²)		ANGLE OF FRICTION	
		UNCURED	CURED	UNCURED	CURED
1	6% + 0.25%	0.63	1.17	7	9
2	6%+ 0.5%	0.77	1.85	8	12
3	6%+0.75%	0.81	1.99	12	13
4	6%+1%	0.75	1.78	9	11
5	6%+1.25%	0.56	1.71	8	10

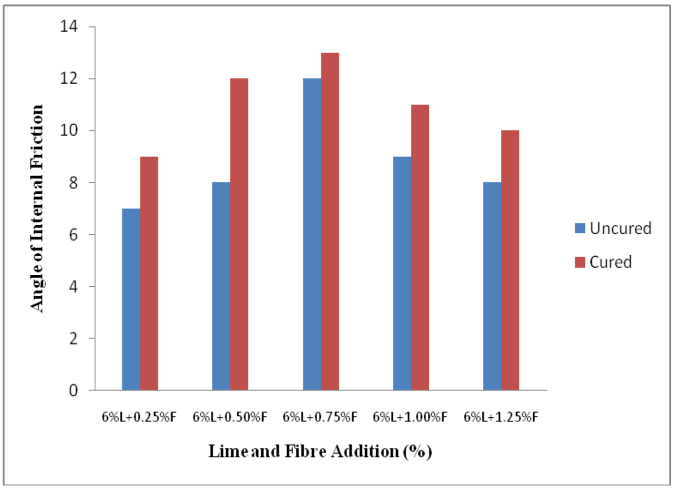

Chart -6: Variation of Internal friction with addition of lime and fibre

6.0. MODEL STUDY OF SQUARE FOOTING

6.1. Tank Size and Experimental Set up

Model test were conducted on laboratory on unreinforced and reinforced soils on triaxial setup. Foundation bed was prepared in test tank of size 28cm*28cm*30cm in volume and the material used for tank was steel plate having thickness of 0.5cm .Model foundation used was a footing of size 5cm*5cm*0.5cm. The applied load was measured using proving ring which were pre-calibrated having a capacity of 2.5 kN.

The load was applied to footing and settlement of soil was measured using dial gauge kept at the top of foundation.

6.2. Test bed Preparation

The soil to be tested were dried, pulverized and mixed with OMC and were kept for 24 hrs with an air tight cover covering the tank. This were done so that water may not get evaporated through it .The soil were filled in layers and were compacted to achieve the required dry density. The foundation model were placed at the top at the centre of tank and dial gauge was fixed at the top of foundation.

Fig -9: Experimental Setup of Model Study

From model test conducted in the laboratory, loads and corresponding settlements were noted and graphs were plotted for both non reinforced and reinforced soils and same were done analytically using software (Plaxis 3D). Load versus settlement curve are shown in Chart -7

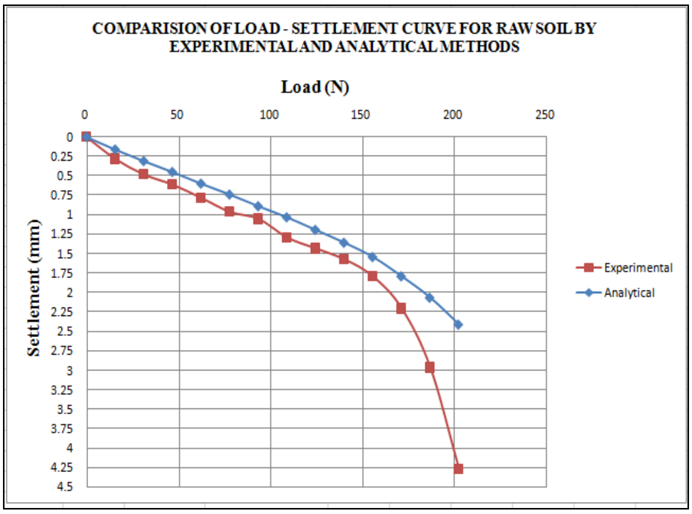

Chart -7: Load-Settlement curve for Non stabilized soil

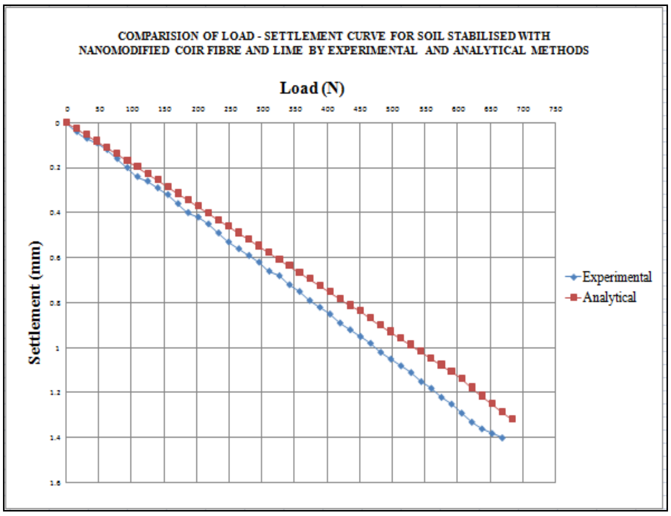

Chart -8: Load-Settlement curve for stabilized soil

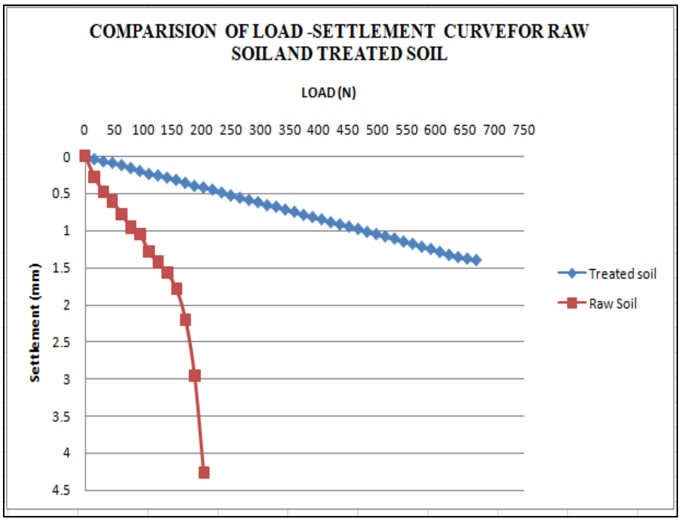

Chart -9: Load-settlement curve for both raw soil and stabilized soil

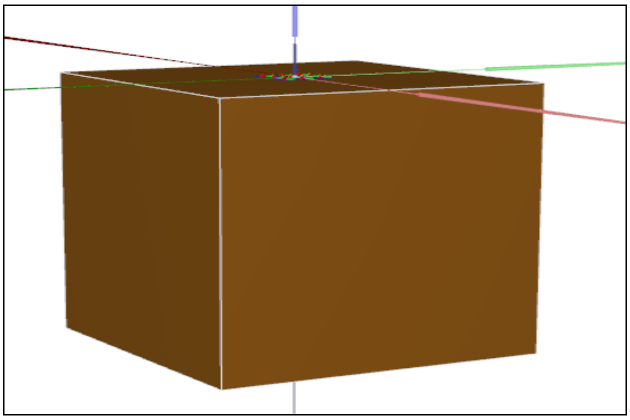

Fig -10: Modelling of footing in plaxis 3D

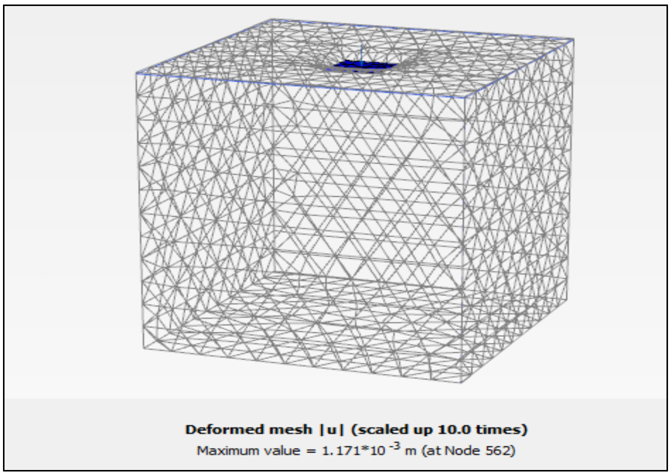

Fig -11: Deformed shape of Unstabilized soil

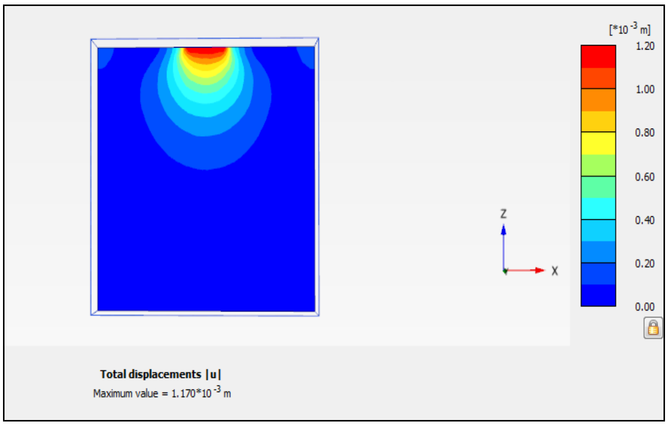

Fig -12: Total Displacement of Unstabilized soil

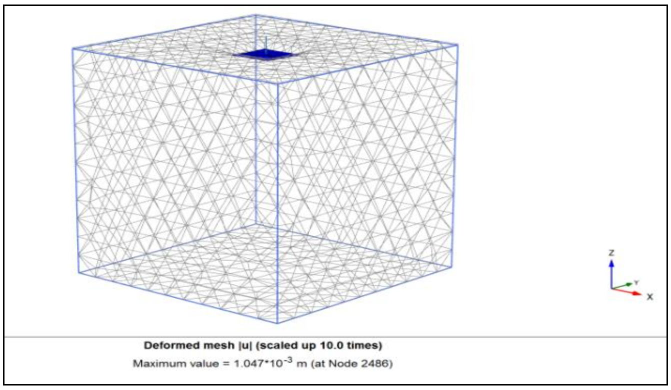

Fig -13: Deformed shape of Stabilized soil

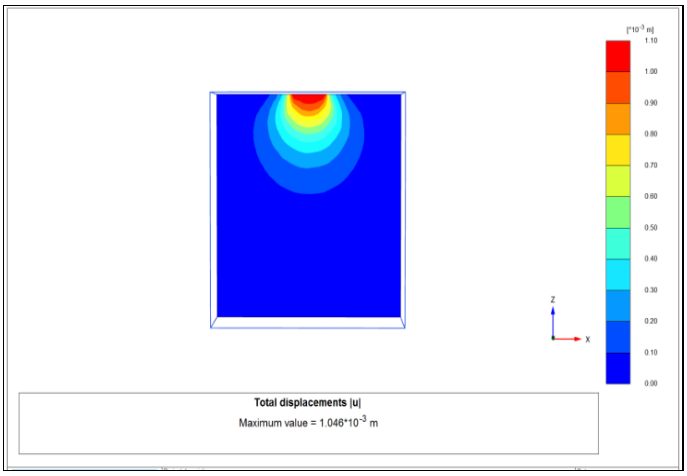

Fig -14: Total Displacement of Stabilized soil

7. CONCLUSIONS

In this study coir fibre was nanomodified through chemical treatment to improve its durability and strength and to be used for long term problems. From the studies conducted following results were drawn

- Nanomodified coir fibre can be used as a reinforcing material.
- The optimum percentage of lime was found to be 6%.
- The optimum percentage of mdd and omc was found to be at 0.75% addition of fibres and lime.
- The decrease in moisture content of soil treated with fibre and lime is attributed to fact that the treatment with ferric chloride and sodium hydroxide decreases the tendency of coir fibre to absorb water.
- The increase in dry density of the soil is attributed to the better interaction of clay with fibre matrix as surface is boarded with nanoparticles.
- SEM results showed that the surface of coir fibre were boarded with crystal particles making surface rougher for treated fibre than that of untreated fibre.
- EDX results conforms the presence of ferric chloride which was seen through the higher peaks for Fe.
- The impregnation of nanoparticles on the fibres helped in increase of shear strength with increase in confining pressure and thereby led to a more ductile behaviour.
- The cohesion increases from 0.43 kg/cm^2 to 0.81kg/cm^2 with the addition of fibres from 0.25% to 0.75% along with lime. Angle of internal friction increases from 7° to 12° with increase of fibres along with lime.

- The cohesion and angle of internal friction increases with increase of curing time. The cohesion increases from 0.81kg/cm^2 to 1.99 kg/cm^2.
- The load bearing capacity of the soil reinforced with nanomodified coir fibres increases around 4 times than that of raw soil for settlement of 1.25mm.
- The analytical results obtained from plaxis were nearly same with that of experimental results.

From the studies it was concluded that nanomodified coir fibre along with lime can be used as a reinforcing material. As this fibre is nanomodified it helps to increase the overall life of coir fibre without affecting its strength. Thus fibres can be used for a long term problems in shallow foundations.

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BIOGRAPHIES

SINDHU A.R.
ASSISTANT PROFESSOR
DEPT.OF CIVIL ENGINEERING
SAINTGITS COLLEGE OF ENGINEERING
KOTTAYAM,KERALA

JUSTIN K JOSEPH
P.G.STUDENT
DEPT.OF CIVIL ENGINEERING
SAINTGITS COLLEGE OF ENGINEERING
KOTTAYAM,KERALA