

EXPERIMENTAL INVESTIGATION AND MODEL STUDY OF SQUARE FOOTING IN PHOSPHOGYPSUM TREATED CLAYEY SOIL REINFORCED WITH SISAL FIBER

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Abstract - Construction of civil engineering foundations on weak clayey soil is highly problematic because of its susceptibility for differential settlement and poor shear strength. Various soil improvement methods have been used so far to enhance the geotechnical properties of soil. Soil reinforcement by adding phosphogypsum is considered as an effective strength improvement technique with regard to its cost effectiveness, waste management and eco-friendly nature. However, use of phosphogypsum alone in clayey soil leads to the brittle nature of the soil. The present investigation has therefore been carried out with sisal fiber along with phosphogypsum to study improvement of the soil in terms of compaction characteristics and shear strength parameters. Use of sisal fiber helps to reduce the brittle nature of the phosphogypsum treated soil and provides a reinforcing effect. Various tests like Standard Proctor tests and triaxial tests were done. Five different percentages of phosphogypsum (5, 10, 15, 20, 25%) and sisal fiber (0.25, 0.5, 0.75, 1, 1.25 %) were tested. A curing period of 2 weeks were also provided for another set of samples. A model study was also conducted to study the load-settlement characteristics of a square footing on both the treated and untreated soil. It was then analyzed using Plaxis 3D software. The results indicated that the optimum value for compaction characteristics and shear strength parameters were obtained at a combination of 15% of phosphogypsum and 0.75% sisal fiber. Investigations using model study and Plaxis 3D also indicated that load carrying capacity of the square footing has increased to a considerable extent.

Keywords: Phosphogypsum, Sisal fiber, Model study, Square footing, Compaction characteristics, Shear strength parameters, Plaxis 3D.

1. INTRODUCTION

In today's world due to the fast increasing Urbanization and modernization, scarcity of land for construction has increased a lot. Due to the increasing value and limited availability of land for construction, the time has come to construct the buildings even in weak expansive clayey soil. The stability of structure depends on soil properties on which it is constructed. The constructions can be economical only if the soil has good load bearing capacity at shallow

depth below the ground surface. In such cases, shallow foundations such as raft foundations or footings can be used. However if the soil available on top surface is weak and strong stratum is found only at greater depth, then foundations such as pile foundation, deep foundation, caisson or well foundation should be used. But construction of such foundations are not economical for small structures. Clayey soils have very low shear strength and high compressibility. They exhibit high volumetric change during alternate drying and wetting. The property of the soil has to be increased before the building has to be built over it.

The concept of reinforced soil, in the modern history, was discovered by Henry Vidal. Reinforcement is a procedure where different types of additives are used to improve the soil properties. The reinforcement reduces the settlement of the soil and increases the load carrying capacity. It also takes a main part in reducing the liquefaction potential of the soil. Reinforced soil will act as a composite material in which reinforcing element have higher tensile strength. Therefore reinforced earth technique is considered as an effective ground improvement method because of its cost effectiveness, easy adaptability and reproducibility.[1]

Additives selected must not be hazardous to the environment, and it should be easily available and less expensive. Here the present is conducting on effect of addition of sisal fiber along with phosphogypsum on the compaction characteristics and shear strength parameters of the soil. The load-settlement behavior of the soil is also studied both experimentally and analytically. The experimental study was conducted using a model tank in laboratory and analytical study was done using plaxis 3D software.

2. LITERATURE REVIEW

Abhijith S, Aruna T (2015) [6] conducted the study on effect of sisal fiber and GGBS on the engineering properties of black cotton soil. Unconfined compression test were conducted by keeping this optimum percentage of GGBS as a constant value and then different percentages (0.25%, 0.5%, 0.75%, 1%, 1.25%) of sisal fiber were added. Maximum strength was obtained when 0.75% sisal fibre was added.

The effect of curing for 7 days, 14 days, 28 days and 90 days were also studied.

Yankai Wu, Yanbin Li, and Bin Niu (2014) [7] analysed the the mechanical properties of silty clay reinforced with randomly oriented sisal fibers using triaxial shear tests. The sisal fibers were cut to 5 mm, 10 mm, 15 mm and then the cut pieces were placed in 10% NaOH solution and dried. Then the triaxial tests were conducted with sisal fibers at 0.5%, 1%, 1.5% of dry weight of soil. The value of cohesion increased to a considerable extent while angle of internal friction is not much affected. The results also indicated that with a fiber length of 10mm and content of 1.0%, sisal fiber-reinforced silty clay is 20% stronger than non-reinforced soil.

Liu Jiasheng, Zhang Juan (2014) [8] done study on the deformation characteristics of sisal fibrous soil. Maximum dry weight was obtained on addition of 0.6% sisal fiber. It also proved that the strong interfacial interactions existed between the sisal fiber and the soil.

Shailendra kumar et al.(2015) [9] conducted the of model tests carried out on embedded square footing which is supported on geo textile reinforced sand bed. The test was conducted on a steel model tank of size 120 cm x 50 cm x 50 cm and a footing of 10 cm square shape was used. A uniform and constant settlement was applied to the square footing for which a hand operated gear arrangement system was used. The settlement of the footing was measured with the help of two LVDTs. The effect of size of geo textile and placement of geo textile below footing on load-settlement characteristics was studied.

Shweikani et al. (2013) [4] studied the radiation dose measurement due to the presence of PG in cement. The measurement was performed using an appropriate radiation exposure model based on radiation capacity (gamma spectroscopy and solid state nuclear track detector CR-39). Results showed that using PG is safe in construction materials.

Sleiman M. Al-Zaidyeen and Arabi N. S. Al-Qadi (2015) [10] conducted tests on the scope of Phosphogypsum in strengthening the different layers of pavements. The main aim this research was to use phosphogypsum (PG), waste produced from phosphoric acid plants, as a strengthening material to improve the engineering properties of the soil. The mixture formula of the material was optimized and the PG dosages 0%, 5%, 10%, 20% and 25% by weight of the soil sample were tested. It was concluded that the optimum percentage of PG was 21% in all soil specimens, particularly for Proctor tests and CBR tests for gravel and the red silty sand.

Degirmenci et al. (2007) [2] investigated the strengthening of soil by the use of phosphogypsum with flyash and cement. Standard proctor tests, Unconfined compressive

strength, and Atterberg limit tests were done on the soil. Different tests showed that the addition of flyash, cement, and PG considerably reduced the plasticity index of the soil. Simultaneously, the maximum dry unit weight increases as the contents of cement and PG increase and decreases with fly ash content. Therefore, the waste by-products, PG and flyash may provide inexpensive and advantageous construction products to a great extent.

Sanusha Babu, Shyla Joseph (2015) [11] conducted experiments on effect of nano materials in kuttanad soil. To study the effect of load settlement behavior of the soil, a model tank of size 25 X 25 X 25 cm was used. Various tests like proctor test and triaxial tests were also conducted and it was proved that there was an increase in shear strength of the soil.

3. MATERIALS USED

The materials used for the tests include Kuttanad clay, phosphogypsum (PG) and sisal fiber (SF). The details of the materials used in this study are given below.

3.1 Kuttanad Clay

In this study, soil sample was taken from a depth of 2 m below the ground level from kuttanad, Alappuzha district, Kerala. Kuttanad area lies 0.6-2.2 m below mean sea level and during monsoon season a large part of it is in submerged condition every year. In the case of Kuttanad soil, it exhibit generally undesirable engineering properties. From the geotechnical point of view, these clays are characterized by its high percentage of organic matter, low shear strength and high compressibility. The properties of the soil were determined as IS specifications. Usually, kuttanad soil is weak and have high potential to cause failures of structures and embankments built over it. Therefore in order to construct structures above these weak soils, modification of its properties using suitable materials is a must. Here study is conducting on effect of addition of Sisal fiber on phosphogypsum treated clay.



Fig -1: Kuttanad Clay

Table -1: Properties of Kuttanad clay

Properties/Parameters	Value/characteristics
Colour	Dark Grey
Natural Moisture Content	168%
Specific gravity	2.34
Grain Size Distribution	
Sand	20 (%)
Silt	15(%)
Clay	65 (%)
Atterberg Limits	
Liquid limit	190 (%)
Plastic limit	93 (%)
Plasticity Index	97 (%)
Compaction Characteristics	
Maximum Dry Density	1.26 g/cc
Optimum Moisture Content	35.8 %
Shear Strength Parameters	
Cohesion (C)	0.192 kg/cm ²
Angle of Internal Friction(ϕ)	8°

3.2 Phosphogypsum

Phosphogypsum (PG) is a waste by-product from the processing of phosphate rock by wet acid method in fertilizer production, which currently accounts for over 90 % of phosphoric acid production[1] . PG has been used as set controller in the manufacture of Portland cement, as a raw material for clinker, as a secondary binder with lime and cement, in the production of artificial aggregates, and in road stabilization [2]. The worldwide production of PG is estimated to be in the range of 100-280 Million tonnes per year [3] . PG production in India is 11 Million tonnes per every year. Upto 15 % of the world PG production is used in the manufacture of building materials[3]. The low utilization of PG may be due to naturally occurring radioactive materials including Ra-226 [2]. It is even banned in several countries[3]. However, in 2009, the Atomic Energy Regulation Board of India approved PG use for construction purposes provided the activity concentration of Ra-226 in it is less than 1.0 Bq/g. Shweikani et al. [4] found that radiation due to addition of PG in cement is within the prescribed international standards for construction materials. PG utilization in soil stabilization by Degirmenci et al. [2]involved its use in combination with cement and, later on, Degirmenci [2] utilized only PG for stabilization of adobe, whereas in this study PG has been used as an additive to lime. The utilization of PG in both fore mentioned cases was more than 2.5 %, whereas in the present study, the maximum dosage of PG was limited to 2 % thereby limiting the study to understanding the effects of PG on lime at low dosage levels. However, Ghosh adopted in his study the combination of lime and PG for stabilization of pond ash, where the PG content was within 1 %.The PG used in the study was obtained from FACT, Cochin, India.



Fig -2: Phosphogypsum

Table -2: Chemical Composition of phosphogypsum[1]

Parameter Composition [%]	Parameter Composition [%]
H ₂ O cryst.	18.0
SO ₂	43.6
CaO	32.0
MgO	0.40
Al ₂ O ₃ + Fe ₂ O ₃	1.82
SiO ₂ ins. in HCl	1.64
Na ₂ O	0.36
P ₂ O ₅ total	1.03
Organic matter	0.26



Fig -3: Sisal Fiber

3.3 Sisal Fiber

For the current research, sisal fiber was collected from Alapuzha, Kerala. The properties of sisal fiber are tabulated in Table 3.

Table -3: Properties of Sisal fiber

Properties	Values
Color	White
Average length, mm	10 mm
Average diameter,mm	0.25 mm
Average tensile strength (N/mm ²)	Average tensile strength (N/mm ²)
Density (g/cc)	1.45

4.METHODOLOGY

In this study, all the soil samples were air dried before the testing in laboratory. Sisal fibers pretreated using NaOH solution before adding in to the soil. These are then cut in into 10 mm length. The standard Proctor compaction test was conducted to obtain the optimum dosage of phosphogypsum. Keeping this optimum amount of phosphogypsum as a constant value, sisal fibers of different percentages(0.25%, 0.5%, 0.75%, 1.0% and 1.25%) were added[5] .Both standard Proctor compaction test and triaxial tests were conducted on these samples.

In order to study the effect of degradation of Sisal fiber, a period of 2 weeks were also provided for curing. Triaxial tests were then conducted on these samples also. Afterwards in order to study the Load-Settlement behaviour of the treated soil a model study was conducted.

4. LABORATORY MODEL TEST

The load carrying capacity of the soil is determined conducting a small scale laboratory model test. A steel box of 25 X 25 X 25 cm dimension with a thickness of 0.5 cm was used in the study. A steel plate of (5*5*0.5) cm is used to simulate the shallow footing. The steel box was filled with soil and placed in the loading machine and then load was applied by the loading arrangement. A calibrated proving ring (maximum capacity of 2 KN) was used to measure the applied load. The settlement due to the application of load was measured by a dial gauge which is fixed on top of the foundation. The Model test was conducted for both the treated soil and untreated soil (at optimum percentage).

4.1 Preparation Of Test Bed

The soil for testing is first pulverized and then air dried. Then it was mixed with water at OMC and was kept for 24 hours for uniform water distribution without allowing any

water loss. The tank was filled in layers, each layer 25 mm thickness. In order to achieve MMD, each layer was given 25 number of blows. The steel plate is then placed centrally above the filled model tank and a dial guage was fixed at its top.



Fig -4: Model tank mounted on triaxial machine

5.RESULTS AND DISCUSSION

5.1. Compaction Characteristics of Clayey soil with Phosphogypsum

In order to determine the compaction characteristics of clayey soil up on addition of phosphogypsum, Standard proctor tests were done with five different percentages of phosphogypsum (5%,10%,15%,20%,25%).

The test results are presented in graphical form below. Highest value of maximum dry density (MDD) was obtained at 15% addition of phosphogypsum. An increase in MDD generally indicates soil Improvement. Initially, Optimum moisture content (OMC) was found to be decreased from 35.8 % to 26.5% and there after it increases upto 35.6 % and afterwards it again decreases.

Table 4: -Influence of PG on MMD and OMC

Percentage of PG	MMD (g/cc)	OMC (%)
PG 0%	1.26	35.8
PG 5%	1.31	26.5
PG 10%	1.39	36.6
PG 15%	1.47	35.6
PG 20%	1.38	28.8
PG 25%	1.36	28

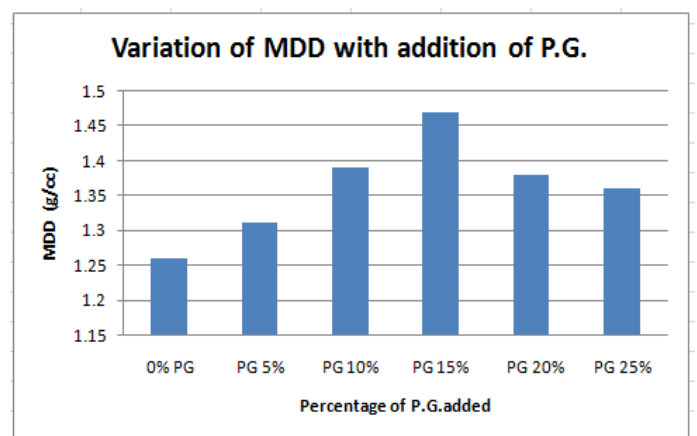


Chart -1: Variation of MDD with addition of PG

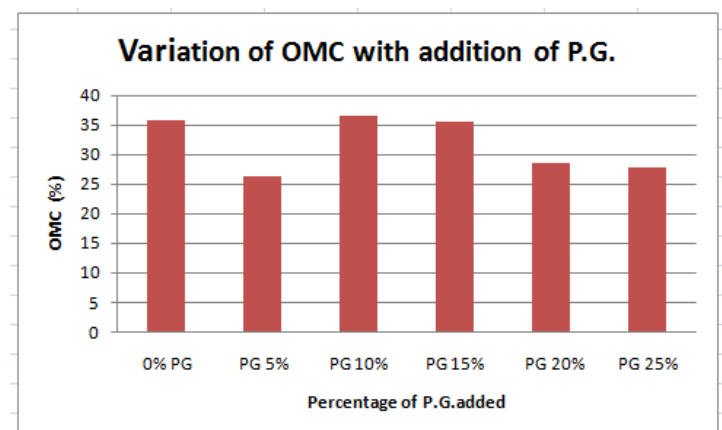


Chart -2: Variation of OMC with addition of PG

Since 15% of phosphogypsum gave the highest value of maximum dry density, it was decided to conduct further

tests by keeping this 15% of phosphogypsum as a fixed value.

5.2. Compaction Characteristics of Clayey soil on addition of both PG and Sisal fiber

Sisal fibers were added in percentages of 0.25%, 0.5%, 0.75%, 1% and 1.25% of dry weight of soil. Up to 0.5% of addition of sisal fiber into the soil, the change in MMD value was not much pronounced and there after it increased to a peak at 0.75 % addition of sisal fiber. Further addition of sisal fiber reduced the MMD value. The OMC value was found to be minimum at 0.75% of sisal.

Table -5: Variation of MDD and OMC on addition of sisal fiber into PG stabilized soil

Percentage of Sisal fibre added into P.G.stabilised soil	MMD (g/cc)	OMC
0 %SF	1.26	35.8
0.25 % SF	1.23	32.5
0.5 % SF	1.23	34.6
0.75 % SF	1.34	31.13
0.1 %SF	1.24	33.23
1.25 %SF	1.28	33.7

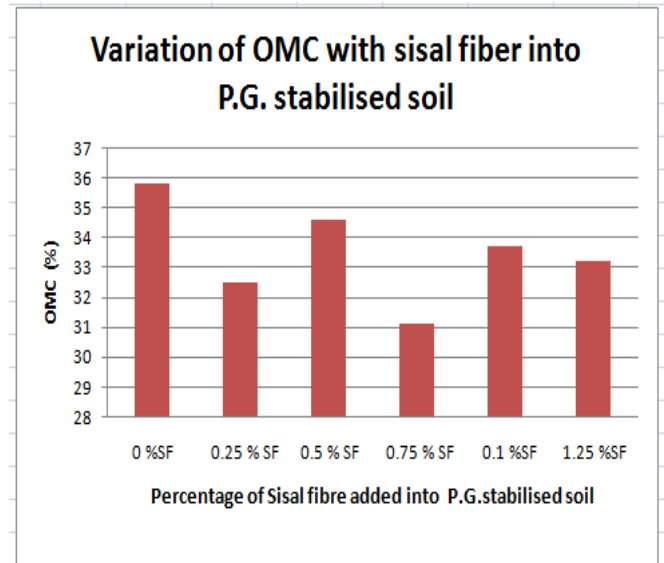


Chart -4: Variation of OMC with PG and Sisal fiber

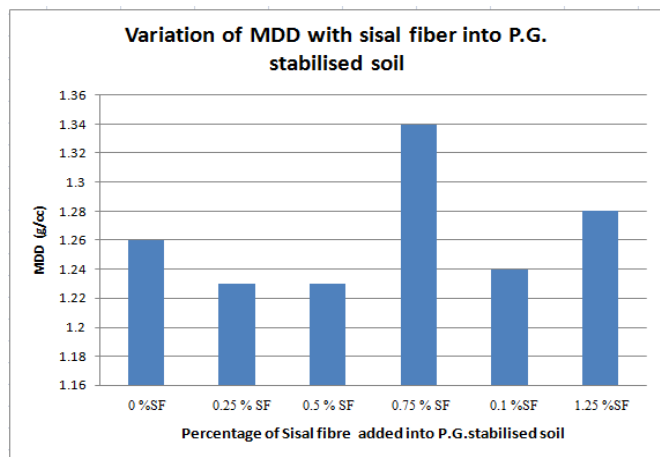


Chart -3: Variation of MDD with PG and Sisal fiber

5.3. Influence of PG and Sisal on Shear strength parameters

Table -6: Variation of Cohesion on adding sisal fiber into PG stabilized soil for zero days Curing.

Percentage of PG and SF	Cohesion (g/ cm ²)	Angle of internal friction(degree)
0 %SF	0.19	8
0.25 % SF	0.26	9
0.5 % SF	0.29	9
0.75 % SF	0.5	13
0.1 %SF	0.31	12
1.25 %SF	0.29	11

Table -7: Variation of Cohesion on addition of PG and sisal Fiber with two weeks Curing.

Percentage of PG and SF	Cohesion (g/ cm ²)	Angle of internal friction (degree)
0 %SF	0.19	8
0.25 % SF	0.49	9
0.5 % SF	0.76	10
0.75 % SF	0.91	12
0.1 %SF	0.53	12
1.25 %SF	0.37	12

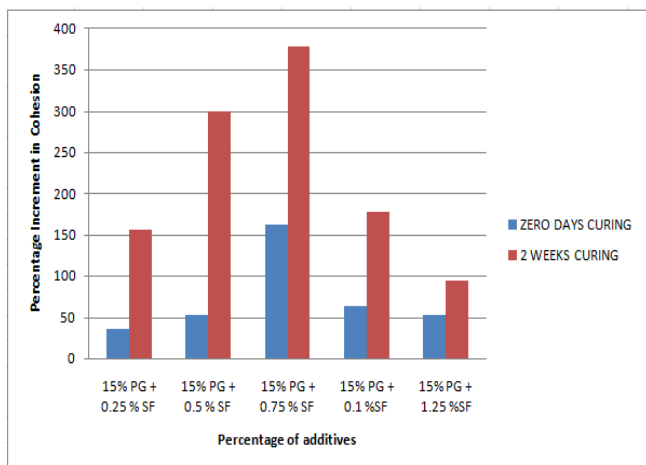


Chart -5: Comparison of Percentage increase in Cohesion of uncured and cured soil.

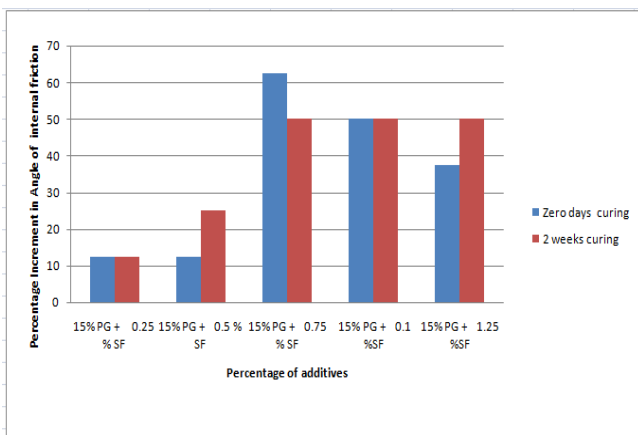


Chart -6: Comparison of Percentage increase in angle of internal friction of uncured and cured soil

5.4. Laboratory Model test Results and Numerical simulation using Plaxis 3D software

The Load and corresponding settlement is noted and graph was plotted with load on X axis and settlement on Y axis. The same was analyzed using Plaxis 3D. Load –Settlement plot for soil without any additives and also for optimum combination of PG and Sisal .

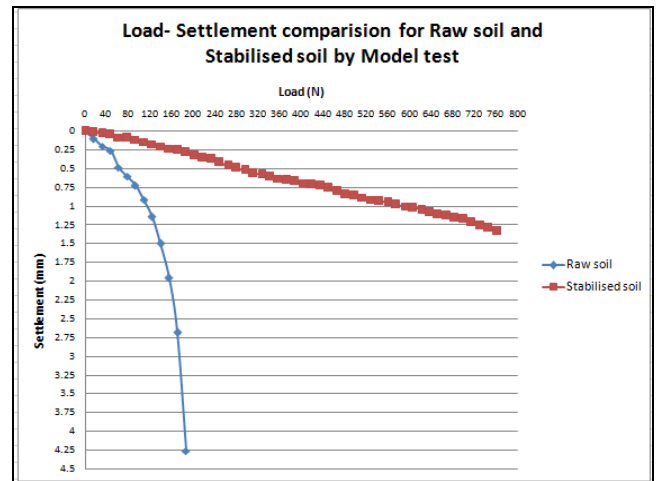


Chart -7: Comparison of Load-Settlement behavior of raw soil and stabilized soil using Laboratory model

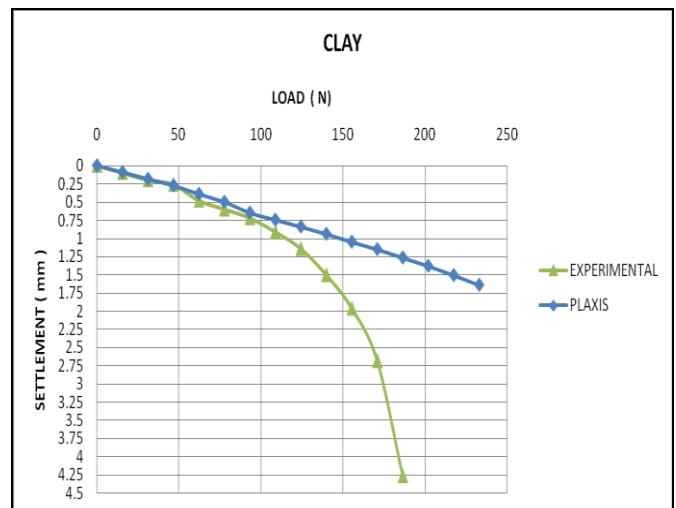


Chart -8: Comparison of Load-Settlement behavior of raw soil using Laboratory model and Plaxis-3D

The graphs shows the comparison between the results obtained from model test and Plaxis software. The results obtained from Plaxis are almost near to model test.

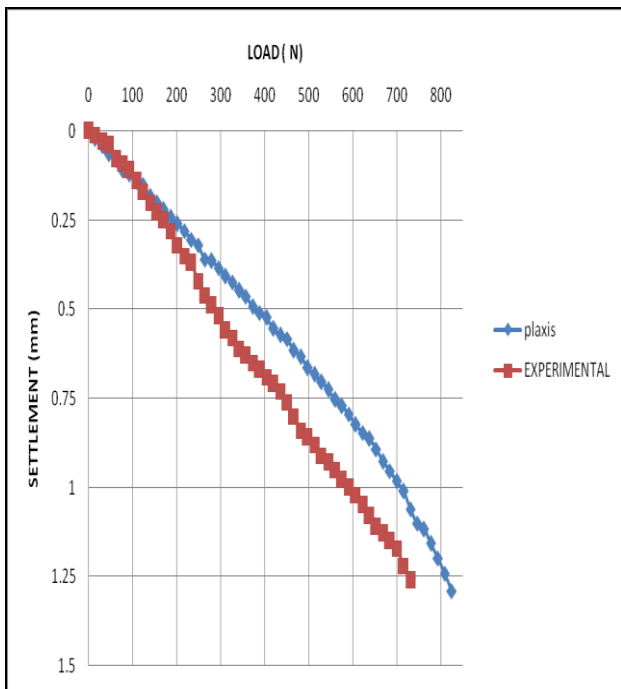


Chart -9: Comparison of Load-Settlement behavior of treated soil using Laboratory model and Plaxis-3D

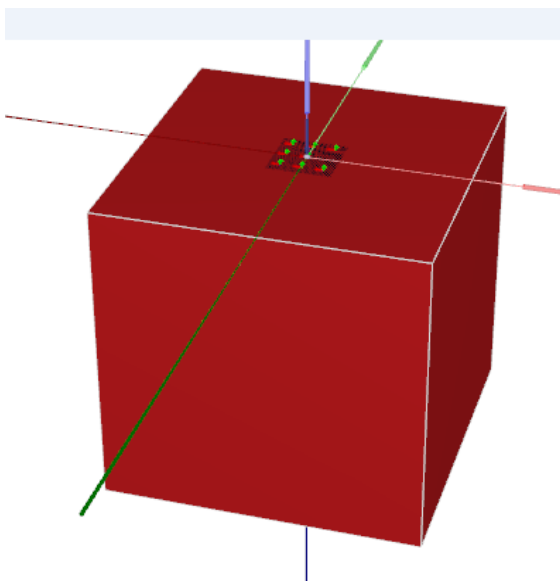
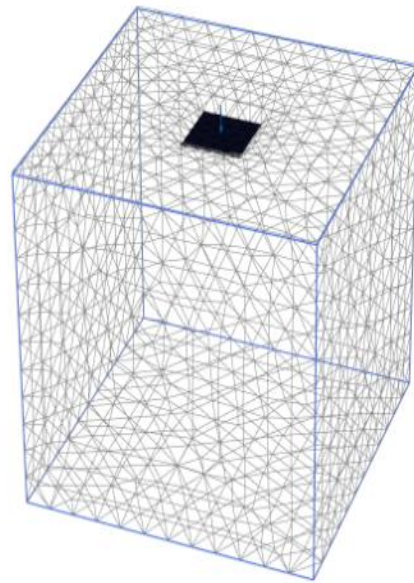
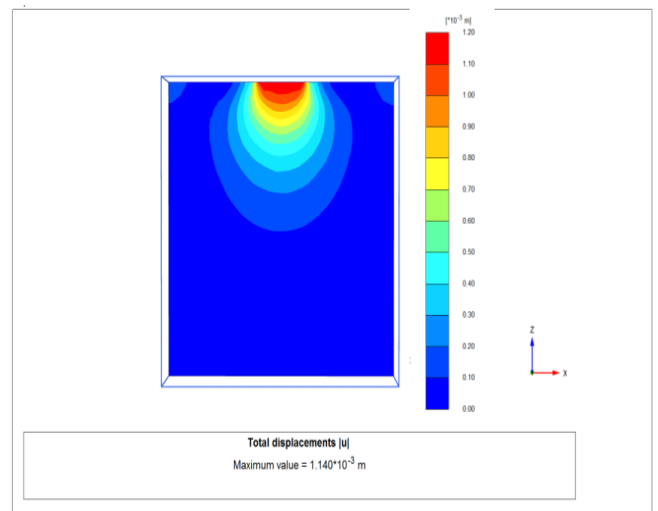


Fig.5.Model for clay



Deformed mesh |u| (scaled up 10.0 times)
Maximum value = $1.151 \cdot 10^{-3}$ m (at Node 10948)

Fig -6: Deformed Mesh for clay



Total displacements |u|
Maximum value = $1.140 \cdot 10^{-3}$ m

Fig -7: Total displacement for clay

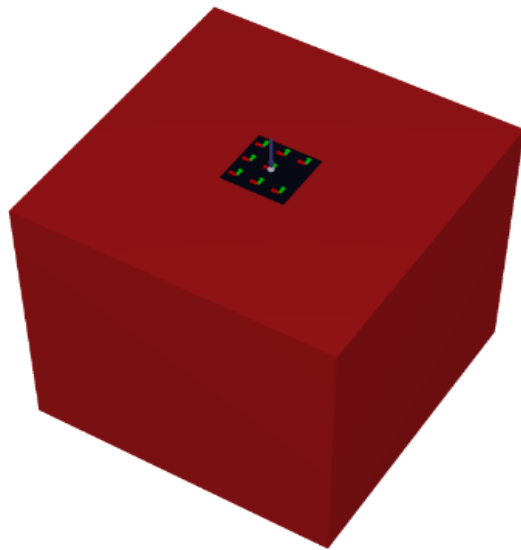


Fig -8: Model for soil treated with PG and SF

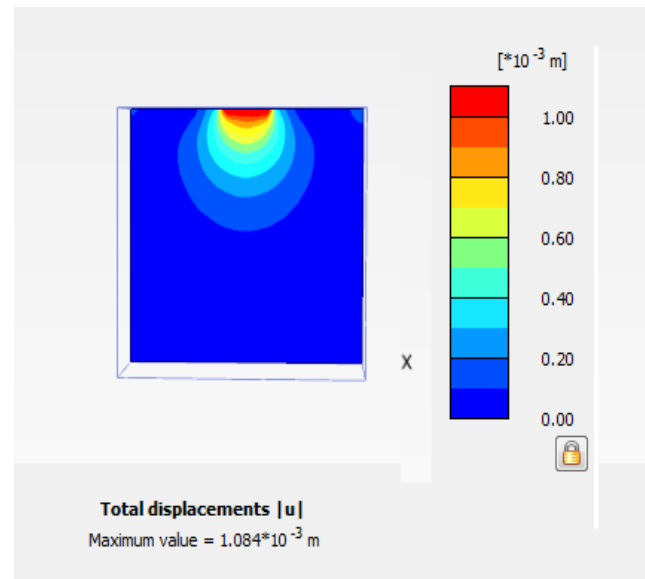


Fig -10: Total displacement for soil treated with PG and SF

6. CONCLUSION

- The value of MDD and OMC was found to be optimum at 15% addition of phosphogypsum.
- The results revealed that soil treated with a combination of 15% Phosphogypsum and 0.75% sisal fiber gives the optimum value of MDD and OMC. The maximum dry density increases from 1.26 g/cc to 1.34 and optimum moisture content decreased from 35.8% to 31.23%.
- For uncured samples with optimum percentages of sisal fiber ,the cohesion value increases about 2.6 times compared to raw soil. For samples cured for 2 weeks, cohesion value increases about 4.7 times.
- The increase in angle of internal friction was not much pronounced for both the cured and uncured samples.
- Load carrying capacity of the soil was found to be increased with the addition of phosphogypsum and sisal fiber. From the Laboratory model tests, about 5.76 times increase in load carrying capacity was found for the treated soil.
- The results obtained from Plaxis 3D are found to be comparative with those obtained from experimental model study.

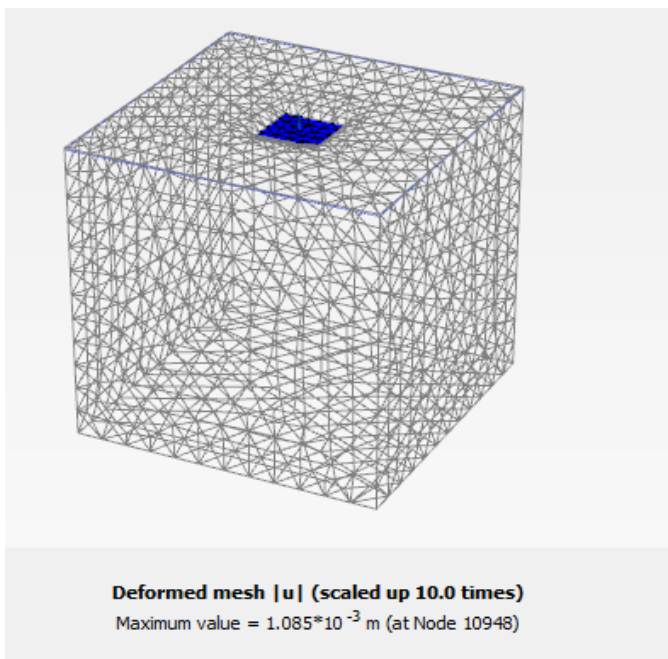


Fig -9: Deformed Mesh for soil treated with PG and SF

7. FUTURE SCOPE FOR STUDY

- Load settlement characteristics can be studied by adding different type of fibers.
- In plaxis software apart from Mohr-Coulomb model other advanced soil models such as Hardening Soil model, Soft Soil Creep model and user defined models can be used.

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