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Stabilisation of Kuttanad Soil Using Terrasil Nanochemical and GGBS

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Abstract. Expansive soil has a propensity to contract and expand in response to changes in moisture content, making it less capable of supporting the infrastructure above it and ultimately failing. By enhancing and stabilising the soil's characteristics, it can be avoided. Nanomaterials are increasingly influencing our daily lives today. The study is aimed to improve the Engineering properties of Kuttanad soil by treating it with nanocompound (Terrasil) as the primary additive and GGBS as the secondary additive. Initially geotechnical properties of Kuttanad soil was determined. Optimum percentage of GGBS and terrasil was determined using laboratory tests and it was obtained as 9% and 0.03% respectively. Finally, the experimental results of prepared soil combinations was analysed to obtain plasticity, UCS, Triaxial and compaction parameters. Addition of optimum percentage of GGBS and terrasil reduced the plastic behaviour of soil and increased the UCS and compaction characteristics. PLAXIS 2D analysis was done for the treated and virgin soil to determine the settlement and FOS behaviour of soil. From the findings, it was determined that the settlement behaviour of treated soil got reduced by 86% and FOS was increased from 1.03 to 2.29.

Keywords: GGBS, Nanocompounds, PLAXIS 2D, Stabilisation, Terrasil.

1 Introduction

Kuttanad is one of the globally important agro-heritages area which contain low lying region of 0.6-2.2m below sea level. Many geotechnical failures necessitate studies on engineering properties. The characteristics of Kuttanad soil's permeability and compressibility have been identified through a variety of studies. According to reports, this soil is unsuitable for construction of foundations, embankments, and unlined canals. so some stabilisation technique should be incorporated to modify the properties[8]. Recently use of Nano compounds are increasing in various applications; In case of soft soil also additions has to be incorporated to improve the properties so that road pavement or embankment or structures can be constructed safely. A nanoparticle are small objects which behave as a whole unit and they comes under a size range of 1-100nm. Nanoparticles behave differently physically and chemically than conventional materials do.

1.1 Soil interaction with nanoparticles

The terrasil chemical is evolving as a new substance for soil stability. Terrasil contains 100 % organosilane atoms, which are water soluble, prevent ultraviolet and heat, they are used as a highly reactive soil improvement technique which make the soil waterproof. Nobody has a clear idea about the fundamental mechanisms of how soil behaviour change when nanoparticle is added to the soil. But some researchers made an attempt to do the same.

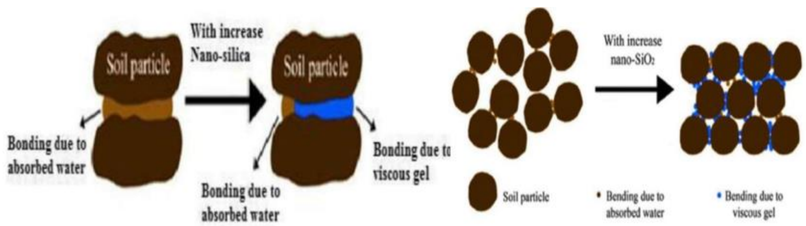

Fig. 1. Behaviour of soil with addition of nanoparticles [7]

Normally soil particles are bonded due to the adsorbed water molecules in between the soil particles. When nanomaterial is added to the soil a viscous gel will be created in between the soil particles. The silica nano-particles present creates a viscous gel like substance through absorption double layer water. Due to this viscous gel the particles get tightly bonded with each other. When compared with untreated soil nano-soil matrix has stronger bonding due to the presence of viscous gel in between the soil particles. In the fig 1 it is observed that as the silica nanoparticle is added to the soil the space between the clay particles reduces and thus improves the interparticle bonding and friction [7].

2 Materials Used

2.1 Kuttand Soil

The samples for the testing programme were acquired from Kerala's Kunnamkeri region, close to the Kuttanad area. The samples of disturbed and undisturbed soil were gathered from 1 m below the surface of the earth The laboratory tests were conducted according to IS 2720- 1965 and determined the geotechnical properties of untreated soil samples. Table 1 shows the test results.

Table 1. Geotechnical properties of soil samples

SLNo	Property	Values
1	Specific Gravity	2.49
2	Atterberg's limits	
	w_l- Liquid limit (%)	93
	w_p- Plastic limit (%)	69
	I_p-Plasticity index (%)	24
3	IS grain size analysis and soil classification	High compressible Silt-MH
4	Engineering properties	
	Density g/cc	1.207
	Water content (%)	90%
5	Unconfined Compressive Strength (kpa)	10
6	Cohesion (kN/m^2)	5.5
7	Angle of internal friction	6.2°
8	Modulus of Elasticity (E)	2357 kN/m^2

2.2 Terrasil

Terrasil nano-chemical used as the stabiliser was acquired from Zydex Industry. According to the technical information offered by Zydex Industries Pvt. Ltd., the recommended dosage of Terrasil is between 0.5 and 1 kg per cubic metre of soil in order to achieve higher UCS values. To find the ideal dosage that corresponds to the maximum strength value, Terrasil percentage are varied in the current work between 0.02 percent and 0.05 percent of soil weight. After mixing terrasil into soil in amounts of 0.02 percent, 0.03 percent, 0.04 percent, and 0.05 percent, a total of 4 soil combinations were created. The terrasil agent is added in a predetermined dosage along with the necessary amount of water to create the initial nanochemical solution. Additionally, the soil mixtures are made by evenly mixing the nano- 14 chemical solution after spraying it on soil. For curing, the mixture was sealed against the air.

2.3 GGBS

GGBS was collected from India Mart. It is a by-product material made during the production of iron. It is primarily made of silicate, alumina, and lime. The ingredients used for the iron production process determine the slag's chemical composition. 40 percent calcium oxide, 35 percent silica, 13 percent alumina, and 8 percent magnesia make up a typical chemical composition.

3 Experimental Investigation

3.1 Optimum Dosage of GGBS

Sample Preparation. The GGBS was mixed with various proportions like 6%, 9% and 12% by its dry weight of soil to obtain the optimum percentage of GGBS. For each percentage samples were prepared and properly sealed to prevent the moisture to come in contact. To determine the optimum value, SPT and UCS test were conducted.

Laboratory Tests. To determine the optimum percentage different experimental investigations was conducted like UCS and SPT.

Unconfined Compressive strength test. The mixed soil samples were filled in a mould and it was extruded and it was kept for 14 days curing. After the curing period UCS test were carried out and it was inferred that the soil samples mixed with 9% GGBS to the dry weight of soil shows a better result when compared to 6% and 12% GGBS mix.

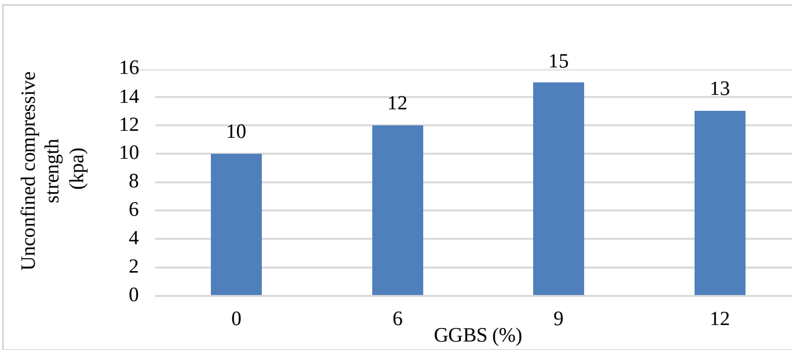

Fig. 2. UCS test results of 6%, 9% and 12% GGBS addition

The relationship between UCS and GGBS percent after 14 days of curing is depicted in Fig.2. From the results it was concluded that 9% GGBS addition shows a better result of 15kpa when compared to zero percent GGBS addition.

Standard proctor test. Samples for the compaction test were made by combining 3 kg of dry soil with various GGBS addition (6%, 9% and 12%), in total 3 samples was prepared. These samples were kept for 28days curing. After curing standard proctor test was done Fig. 3 shows the results obtained. Soil samples with 9% GGBS addition shows a better result with a MDD of $1.416 g/cc$ and the OMC value of 21%. As the GGBS percentage increases the MDD increases and OMC decreases up to a particular limit of 9% and beyond that the MDD got dropped down and OMC value got raised.

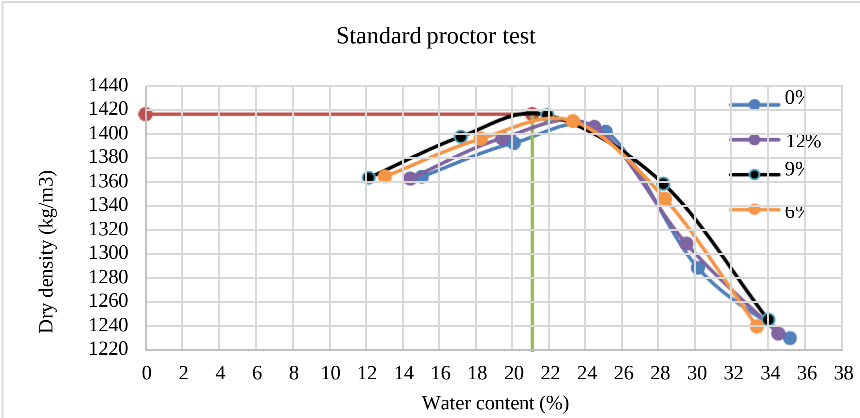

Fig. 3. Standard proctor test results

3.2 Optimum Dosage of Terrasil

Sample Preparation. Terrasil dosage varies in the current work and ranges from 0.02 percent to 0.05 percent of the weight of the dry soil. Initially ideal percentage of GGBS was mixed to the soil, later terrasil was mixed with the OMC and it was inputted to the soil-GGBS mixture. Later water was incorporated to the mix to attain field condition. Fig 4 shows the soil-GGBS-terrasil sample mix prepared with different dosage of terrasil (0.02%, 0.03%, 0.04%, 0.05%) for conducting the laboratory test. Following a 7-day curing period, laboratory tests were conducted on these samples to determine the ideal terrasil percentage and the level of soil improvement.

Laboratory Test. To establish the optimum terrasil dosage, various laboratory tests including SPT, UCS, triaxial, and Atterberg limits tests were carried out.

Standard Proctor test. This test was done for each terrasil dosage to identify the compaction characteristics of the soil. 3kg of soil samples were taken for each dosage of terrasil, in total 4 samples of different dosage like 0.02%, 0.03%, 0.04% and 0.05% was taken for the test. Fig. 4 shows the results obtained after conducting standard proctor test. Soil mixed with 9% GGBS and 0.03% terrasil shows a peak value of 1.507g/cc and OMC value reduced to 17%. From the graph it is visible that as the terrasil dosage increases the maximum dry density increases up to a particular limit of 0.03% terrasil addition beyond that the value decreases. So the optimum percentage of terrasil addition was observed as 0.03%.

Atterbergs Limits test. To ascertain how soil behaves plastically, the Atterberg limits test was performed. Using the Casagrande's liquid limit apparatus the test was conducted. Table 2 shows the Atterberg limits results of nanochemical treated soil. From the test results it was inferred that as the terrasil dosage increases liquid limit and plastic limit values decreases. The trend of plasticity index values is in such a way that initially it starts decreasing up to a particular dosage of 0.03% terrasil and beyond that it increases. Thus it is inferred that the plastic behavior of soil starts decreasing up to the optimum value

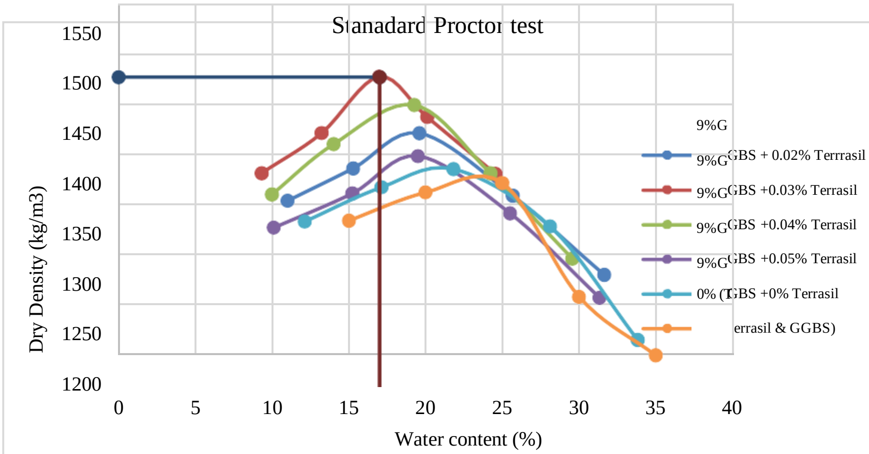

Fig. 4. Standard Proctor test results of terrasil and GGBS treated soil

Table 2. Atterberg limits test results of terrasil and GGBS treated soil

Soil Type	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (%)
Soil + 0% (GGBS , Terrasil)	93	69	24
Soil + 9% GGBS + 0.02% Terrasil	86	66	20
Soil + 9% GGBS + 0.03% Terrasil	83	65	18
Soil + 9% GGBS + 0.04% Terrasil	81	62	19
Soil + 9% GGBS + 0.05% Terrasil	80	59	21

Unconfined Compressive Strength Test. UCS of each dosage soil samples was tested. Fig.5 shows the UCS test results of treated soil. From the graph it is clear that initially the UCS starts increasing up to a particular limit of 0.03% after that it starts decreasing. For virgin soil the UCS value was 10 kPa whereas for treated soil the value increases up to 40kPa, whereas for 0.04% and 0.05% terrasil the value reduces to 25 and 20kPa. Thus it was concluded that only up to optimum terrasil addition it indicates an improvement in the unconfined compressive strength value by 30 kPa beyond that the value starts decreasing.

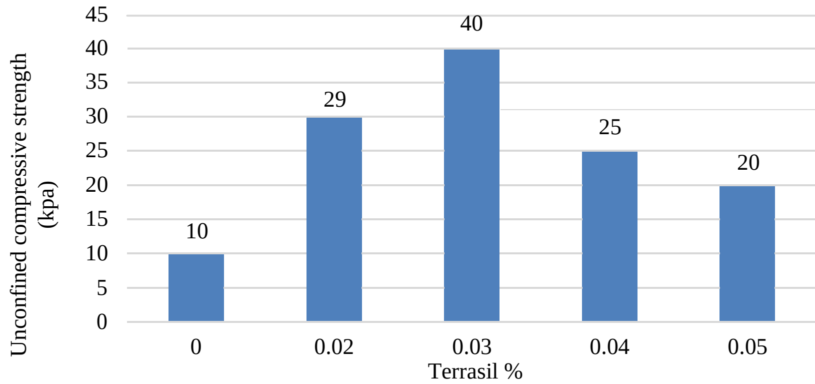

Fig. 5. UCS test of GGBS and terrasil treated soil

Triaxial Test. It was conducted in order to determine the shear strength characteristics. 3 soil samples were taken and different confining pressure of 50kN/m^2, 75kN/m^2 and 100kN/m^2 was applied. Fig.6 shows the triaxial test results of terrasil treated soil. Trial 1, 3 and 2 correspond to the Mohr circle of 50, 75 and 100$kN//m^2$ confining pressures respectively. The equation of mohr envelope is given as y = 0.1586x + 20.2 and the value of cohesion and angle of internal friction is obtained as 20.2kN/m^2 and 9.01kN/m^2.

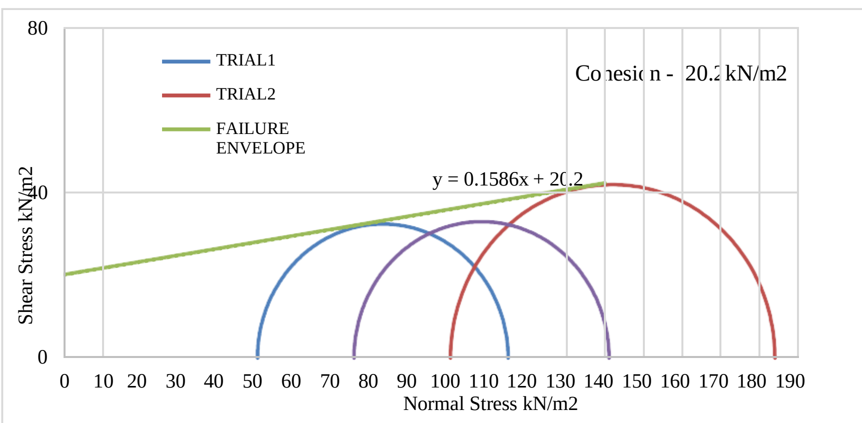

Fig. 6. Triaxial test results

4 Numerical Analysis

The numerical modelling was done using the two-dimensional Geotechnical finite element analysis Plaxis 2D. The lateral extents of the model were taken as follows $xmin$ = -50 m, $xmax$ = 50 m, $ymin$ = -50 m, $ymax$ = 50 m. An embankment rests here on both treated and untreated soil. The treated and untreated soil is modelled up to a depth of 10 metres below the surface, and a subsoil depth of 20 metres is provided below that.

4.1 Material Properties

Table 3 shows the material properties of soil interfaces inputted in PLAXIS 2D. Mohr Coulomb is used as the material model for all soil interfaces. Different line loads of 9, 12, 13.5 and 15 kN/m^2 was applied along the top of the embankment. These line loads was applied to the embankment using a plate element. Table 4 exhibits the material properties of plate element applied.

Table 3. Material properties of soil interface

Parameters	Embankment	Untreated Soil	Treated Soil	Subsoil
Young's Modulus, E (kPa)	20000	2357	6964	50000
Saturated Unit weight, $\gamma_{sat}(kN/m^3)$	18	12.51	14.49	21
Unsaturated unit weight $\gamma_{unsat}(kN/m^3)$	16	14.32	18.05	17
Angle of internal friction, Φ (°)	31	6.65	9.01	35
Cohesion, c (kN/m^2)	5	5.5	20.2	1

Table 4. Material property of plate element [9]

Plate Type	Type	EA (kN/m)	EI (kN/m)	d (m)	υ
Steel	Plastic	5.72E+0.7	2040	0.02	0.3

4.2 Modelling and Meshing

The above mentioned geometry and material properties was inputted in PLAXIS 2D and the embankment resting on soil was modelled. Fig.7 shows the 2D model and the meshed of soil generated based on the above properties. In this analysis medium size mesh is used.

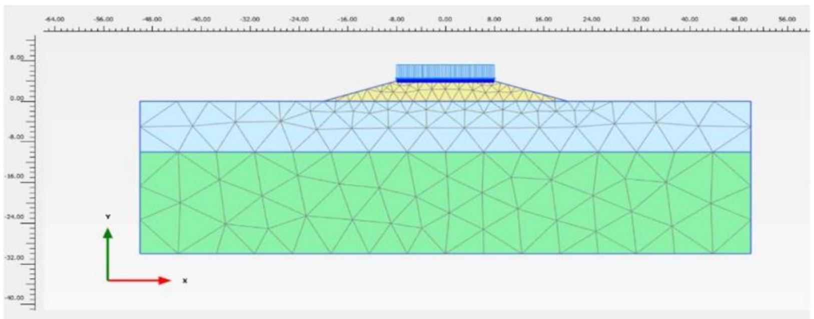

Fig. 7. Meshed Structure of 2D model generated in PLAXIS 2D

4.3 Analysis

Settlement. Line load of 9, 12, 13.5 and 15kN/m^2 was applied on the top of the embankment for both treated and untreated soil. Fig. 7 indicates the settlement behavior of both treated and virgin soil. From the graph it is clear that for untreated soil the displacement value is greater than 0.5m whereas for terrasil-GGBS treated soil the value is less than 0.15m. From the graph we can see that as the load increases there is huge settlement increases in case of untreated soil, whereas for treated soil the settlement increases slightly as the load increases. Fig 4.27 and 4.28 shows the software results obtained for treated and untreated soil.

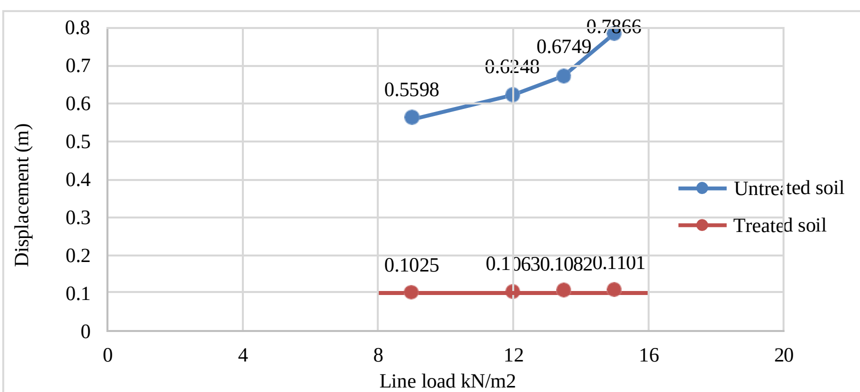

Fig. 8. Load Vs Displacement graph for treated and untreated soil

Factor of Safety. It is expressed as the safety margin of the slopes. Factor of safety indicates the reliableness for geotechnical structures such as embankment dams and soil slopes. FOS of embankment resting on treated and untreated soil was analysed.

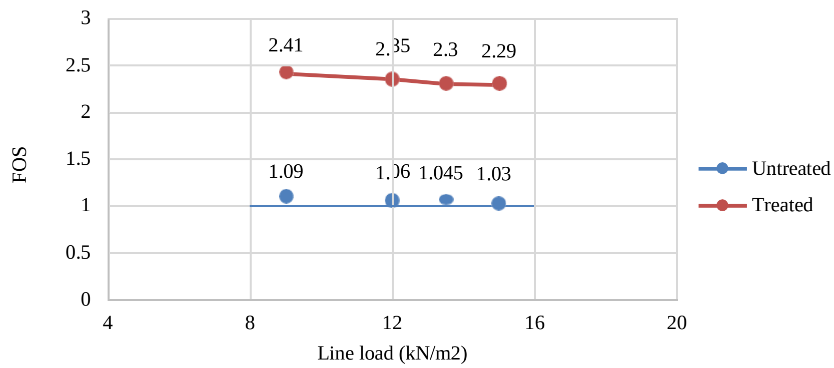

Fig. 9. FOS Vs Load graph for treated and untreated soil

Fig.9. shows the FOS Vs load graph of treated and untreated soil under different loading cases. From the graph it is clear that the FOS of treated soil is greater than 1.5 therefore it is safe, whereas for untreated soil it is less than 1.5 but greater than 1 therefore it is stable but not in a safe condition.

5 Conclusions

The studies looked at how terrasil nanochemical and GGBS affected the characteristics of Kuttanad soil. The economic aspects of terrasil was also analysed using the datas collected from zydex industry. For 20kg terrasil nanochemical it cost 19,800 ₹, since we are using only a small quantity of product the overall cost will be very low and also since this product does not produce any harmful effect it is considered as an economic and environmental friendly stabilising material. Experimental investigation was done and identified the properties of Kuttand soil. Later ideal dosage of terrasil and GGBS was added to the virgin soil and conducted some laboratory test to identify the improvement in the properties. Numerical analysis of treated and untreated soil was done and analysed the settlement and FOS parameters. The findings of the current study led to the conclusions below.

1. The optimum percentage of GGBS and terrasil was obtained as 9% and 0.03% respectively by conducting different laboratory tests like SPT, Atterberg limits test and UCS test.

2. When 9% GGBS was mixed with soil the MDD value increased by 0.4% and OMC reduced by 12% similarly soil mix of 9% GGBS addition and 0.03% terrasil addition improved the compaction characteristics by 7% and reduced the OMC value by 29%.

3. The plasticity index value reduced from 24% to 21% by the addition of GGBS and Terrasil, it states that the soil become less plastic by the addition of optimum percentage of terrasil (0.03%) and GGBS (9%). Thus, it is established that terrasil increases soil stiffness.

4. The plasticity index value reduced from 24% to 21% by the addition of GGBS and Terrasil, it states that the soil become less plastic by the addition of optimum percentage of terrasil (0.03%) and GGBS (9%). Thus, it is established that terrasil increases soil stiffness.

5. The shear strength parameters obtained from the triaxial test like the c and ϕ values has increased by the addition of optimum dosage of terrasil and GGBS. Thus the shear strength of treated soil increases.

6. The UCS values of GGBS-terrasil treated soil increases from 10kPA to 40kPa.

7. From the PLAXIS 2D analysis it was observed that the FOS of untreated soil was less than 1.5 and whereas for treated soil it was in the range of 2.29-2.41 which was safe when compared to untreated soil. For untreated soil the value is greater than 1 therefore it is stable but not in safe condition.

8. The settlement behaviour of treated soil has reduced by about 86%. There is no much settlement observed even if the load is increased.

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