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An Experimental Study on Corex (Steel) Slag Reinforced with Terrazyme Treated Clay for Improvement of Soft Soil

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Abstract

Stability and settlement problems are common for foundations constructed on soft soils. In major parts of the world, ground improvement techniques have been used to mitigate these challenges. This research aims to stabilize the soft soils using corex steel slag blended with terrazyme treated clay. The corex steel slag is an industrial waste formed during the extraction of steel from ores through the corex process. The corex slag of sand size in the form of columns have been used to improve the load-carrying capacity of the soft soils and to control the settlement. To increase the stiffness of the corex slag columns, the terrazyme treated clay was mixed with the corex slag. The terrazyme is an eco-friendly and sustainable organic liquid and it is fully soluble in water. To prepare the terrazyme-processed clay gel 0 to 3 % of terrazyme dissolved in water was used. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for terrazyme treated clay were determined through the compaction tests. Appropriate proportions of corex slag and terrazyme treated clay with a suitable curing period were obtained from unconfined compression tests. A series of laboratory model plate load tests for 3 foundation shapes were performed on soft soil, stabilized with a blend of corex slag and terrazyme treated clay. Improvement in the MDD with a reduction in OMC was noticed when terrazyme was added to soft soil. Unconfined Compressive Strength (UCS) value for corex slag increased with an increase in the content of terrazyme treated clay. Model plate load tests showed significant improvement in the load-carrying capacity of soft soil.

Keywords: Corex slag, Model test, Soft soil, Terrazyme, UCS, Rest on the sand

Introduction

Soft soil exhibits high compressibility which leads to differential settlement of the foundations. An extra structural element is required to support the foundations on such soils. Low bearing capacity is another drawback of the soft clays, resulting uneconomical design of the foundations. Soft clays behave like sponges in which the swelling and shrinking cycle continue with the alteration of water content. The stability of civil engineering structures is always puzzling for Geotechnical engineers whenever they encounter such problematic soils. Replacing such soils with quality soil is a time-consuming and costly solution. Reinforcing the weak soils is an acceptable method to support the structure on it. Cement, lime, fly ash, coir fiber, synthetic fiber, etc., are the common materials used to improve the strength characteristic of the soft clays.

Terrazyme is a natural bio- enzyme extracted from vegetation such as sugar cane. It is a non-corrosive non-toxic, non-flammable echo friendly organic liquid, soluble in water. It improves the engineering properties of soft soils by facilitating higher compaction, an increase in density, and stability. Enzymes catalyze the reaction between the clay and the organic cations and accelerate the cationic exchange process to reduce adsorbed layer thickness.

The use of industrial by-products for the improvement of weak soils is an acceptable trend. It reduces the disposal exercise and minimizes the environmental issues. Corex slag is the by-product in the production of steel by the corex process. It is available in sand-size particles also and possesses the cementation property. Due to its bulging property, corex slag was mixed with soft soil to develop a stiffer column.

Terrazyme alone cannot stabilize cohesionless granular material. Terrazyme diluted in water is applied to the clay to form the gel. So, the paste of clay with terrazyme is prepared to construct a stiffer granular column.

When terrazyme is blended with clayey soils, it not only increases the UCS but also enhances the soaked and unsoaked California Bearing Ratio (CBR) value [1-8]. Reduction in the liquid limit, plasticity index, and shrinkage indices was noticed when 200 mL terrazyme was mixed in 1.5 to 3.0 m^3 soil at 0.5 m^3 interval [9]. In another attempt, improvement in the Atterberg limit for black cotton soil was found when terrazyme was mixed at 0.5 mL per 100 mL of water content [10]. Field emission scanning electron microscopy (FESEM) shows dense packing of particles for soil samples treated with earth enzyme and terrazyme [11]. Microbiologically induced calcite precipitation (MICP) is a biological mechanism that can be used in a variety of geotechnical engineering applications [12]. Thomas and Rangaswamy [13] prepared the blend of soil from Kaloor, Kochi, and enzymatic cement-treated clay to study the UCS value. During the test, the stress-strain curve shows peak stress than the virgin soil at 28 days of curing with 200 to 281 % in UCS value. Reduction in swelling and shrinkage in highly expansive soil with 75 % control in dust formation was obtained in the blend of bio-enzyme and clay. The aggregate-free surface may be promoted as bio-enzymes to improve locally available materials [14]. Compress earth block prepared from the blend of lime, cement, and enzyme gave a 50 % increment in wet compressive strength at 2 years of aging compared to the block prepared without enzyme [15].

Sand compaction piles, sand columns, or granular piles are also considered useful methods for the improvement of soft clays. Granular columns circular in cross-section and in a group improves the bearing pressure and reduction in a settlement. Tunis soft soil reinforced at a constant area replacement ratio of 22 % is found that as the number of columns increases, improvement in undrained shear strength and effective angle of internal friction is observed [16]. Expansive soil was reinforced with a single sand column of 90 and 110 mm diameter with a depth of 150 and 300 mm and a group of such sand columns were placed at a different spacing of 3-times diameter and 4-times diameter. Experimental results showed that the load-carrying capacity of expansive soils increased as the diameter and depth of the sand column increases [17]. In the lack of lateral support, there will be deformation of sand pile used for the reinforcement of soft soils. Geo-synthetic material provides lateral support surrounding the sand column and improvement in load carrying capacity is found due to the confinement of the sand column [18]. The load-carrying capacity of the granular pile increases up to L/D ratio 4 to 5. Twenty % improvement in the strength of the granular pile was found when it was placed with randomly mixed fiber at 0.5 % [19]. Sand piles inserted in soft clay with/without skirts shows remarkable improvement for circular footing at shallow depth. Reduction in the vertical settlement was also observed when soft clay was reinforced with sand piles with confine skirts [20]. Trench filled with granular material not only provides a strong base but also distributes the load on a wider area with improvement in the bearing capacity [21]. Shear strength of sand and spacing of sand compaction piles (SCP) plays a significant role in the enhancement of strength for clayey soil [22]. Improvement in the load-carrying capacity by 8.3 % for 3D to 4D spacing, 19.8 % for 3D to 5D spacing, and 10.6 % for 4D to 5D spacing are found in the 2×3 pile group at an aspect ratio of 25 [23].

All the above literature demonstrates the application of terrazyme in poor or weak soils to improve the CBR, UCS and Atterberg limits. Some researchers have applied granular material in the form of sand piles or columns. This paper presents experimental work on corex slag reinforced with terrazyme treated clay. UCS tests were performed on different proportions of corex slag and terrazyme treated clay aiming to obtain appropriate proportions between corex slag and terrazyme treated clay. Model plate load tests were conducted with 3 different shapes of footings having nearly the same area on soft soil, stabilized with various numbers of corex slag and terrazyme treated clay columns. Load-settlement responses were studied to evaluate the effects of the shape of the footings and the numbers of the columns.

Materials and methods

Materials

Soft soil

The soft soil was collected from the bank of river Tapi, near village Bhatpore, District Surat, Gujarat India. Auger boring method was used to collect the samples at depth 5.5 to 6 m. Representative samples were sealed in polythene bags for the protection of field moisture. Sealed materials were taken to the laboratory for the determination of engineering properties.

Figure 1 Corex slag with different size.

Corex slag

The ESSAR steel plant at village Hazira, District Surat, Gujarat, India, produces high-quality steel. Corex slag is the by-product of steel production through the corex process. Corex slag was obtained from the ESSAR steel plant and mechanical sieve analysis was performed after the oven-drying of corex slag. **Figure 1** shows the corex slag in different sizes.

Terrazyme

Terrazyme is an enzyme in the form of organic liquid extracted from vegetation such as sugar cane. It is an eco-friendly, non-toxic material obtained from Dhara Biotech, near village Vasad, District Vadodara, Gujarat, India.

Test and methods

The investigation was conducted using standard equipments at the Geotechnical Engineering laboratory of the Civil Engineering Department, SVNIT Surat, India. All the experiments in this study were carried out according to the Bureau of Indian Standard Codes. Preliminary tests including field moisture content, specific gravity, and sieve analysis for particle size, Atterberg limits, and MDD at the OMC were performed to determine the index properties and classification of natural soil. Shear strength was determined through the vane shear test.

Research experiments

Research work was divided into 3 stages. In the 1st stage, compaction tests were done on the soft soil with different content of terrazyme diluted in water. In the 2nd stage, an appropriate blend was selected by performing a total of 48 UCS tests. In the 3rd stag specimens prepared with corex slag and terrazyme treated clay were applied in a group to determine appropriate numbers for improvement of the soft soil.

Compaction test

Compaction tests were performed to assess OMC and MDD in accordance with IS 2720 part 8 to confirm the optimum content of the terrazyme. A total of 40 lightweight compaction tests with different terrazyme contents from 0 to 3 %, were performed.

Unconfined compressive strength

Soil passing through 75 µ sieve (clay) and corex slag were mixed in different proportions. For all proportions, the required content of clay was added into corex slag and mixed thoroughly in dry condition. Terrazyme diluted in the water, was added to a dry mix of corex slag and clay. The water and terrazyme were taken as per the compaction test results of OMC and MDD. The homogeneous blend was poured into the UCS mold (50 mm diameter and 100 mm height) in 3 layers, gentle compaction was applied for the expulsion of air. The plastic wrapper was applied on extracted specimens from mold and placed into the incubator for different curing periods of 7, 14, 21 and 28 days. The UCS tests were performed after the specified curing period and three (3) specimens were tested for each proportion and curing period. At lower clay content the load was measured at an interval of 0.1 mm deformation, and with higher clay content measured at 0.25 mm deformation. The load was applied at a rate of 1.2 mm per min. The loading was applied up to maximum reading on the load cell, and up to the failure of the specimen. **Figure 2** shows the specimens with a plastic wrapper.

Figure 2 Specimens of corex slag mixed with terrazyme treated clay for UCS tets.

Application of specimens in group

The ground was modeled inside the rigid steel box attached to a loading frame. A schematic diagram of the loading frame is shown in **Figure 3**. The steel box has a square area of 600 mm side and a depth of 600 mm. To avoid any lateral movement the sides of the steel box were stiffened by vertical angle.

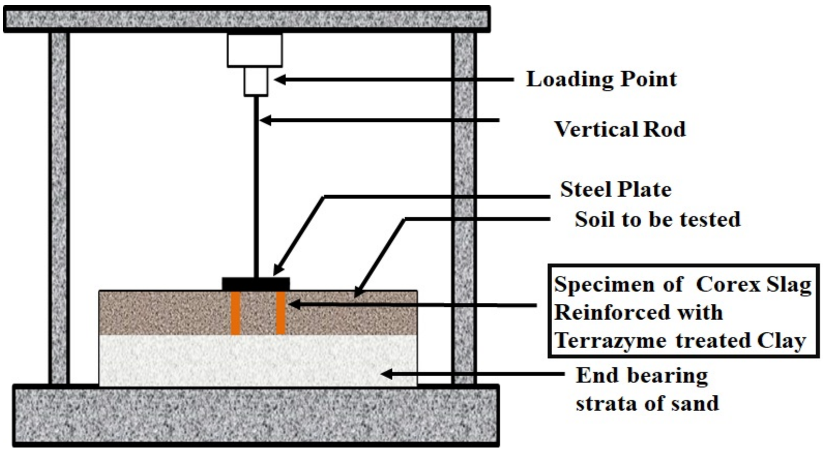

Figure 3 Schematic diagram of the loading frame.

The specimens were assumed as end-bearing columns. Dense sand strata were used to rest the specimens in the group. To create dense sand ground a relative density of sand was determined. The corresponding density of sand was 16 kN/m^3, the loose density of 1.3 g/cc, and dense density 1.71 g/cc, relative density 30 %. The sand was placed inside the steel box in lifts; each lift was 50 mm in height. The weight of each lift was calculated with a dense density of 1.71 g/cc. After pouring the sand by rainfall method the sand was compacted, each lift height was maintained and the surface was leveled. In the same way, all lifts were continued until 450 mm depth from the bottom was achieved. The field condition was created inside the steel box, on the dense sand with 100 mm in height. The field condition was created in 2 lifts of 50 mm each. Soil collected from village Bhatpore near river Tapi was placed at field moisture content. Plate load tests were performed with a 1 cm thick steel plate. Three plates in different shapes and dimensions were used. Rectangular (32×50 cm), circular (45.1 cm diameter) and square (40 cm side) with the nearly same area.

Installation of specimens in symmetrical positions

For the accurate and symmetrical positions of specimens in the group, 8 wooden boards as shown in **Figures 4** and **5** were prepared. **Figure 4** shows 4 numbers of circular wooden boards with a diameter of 45.1 cm. Board A used for 4 and 8 specimens. An alternate pocket is used for the installation of 4 specimens, while for 8 specimens all the pockets shown in plate A were used. Board B is used for 6 specimens, while boards C and D were used for 10 and 12 specimens. In **Figure 5** plate E shows a square wooden board of 40 cm side for installation of 4, 6, 8 and 12 specimens. The 1st 4 specimens were installed in pockets numbered 1 to 4. Same way 6, were installed in 1 to 6, and 8 were installed in 1 to 8 pockets shown in **Figure 5,** all the pockets were used to install 12 specimens. Board F was used for 10 numbers of specimens in the square plate. In **Figure 5** board G shows a rectangular wooden board with 32×50 cm dimensions, for the installation of 4, 6, 8 and 12 numbers specimens. The same pocket numbers were used for the installation of 4, 6, 8 and 12 specimens as discussed for the square board E. Board H was used to install 10 numbers of specimens in a rectangular plate. For the development of geometrical positions of specimens, on top of the soil, the wooden boards were placed on the top of the soil for a 1 to 2-min duration. A hollow steel pipe with a 50 mm outer diameter was lowered gradually. The soil inside the hollow pipe was removed with a helical auger. The hollow steel pipe was removed gently and the specimens were lowered in the prepared model. The same procedure was adopted to install the specimens in the positions.

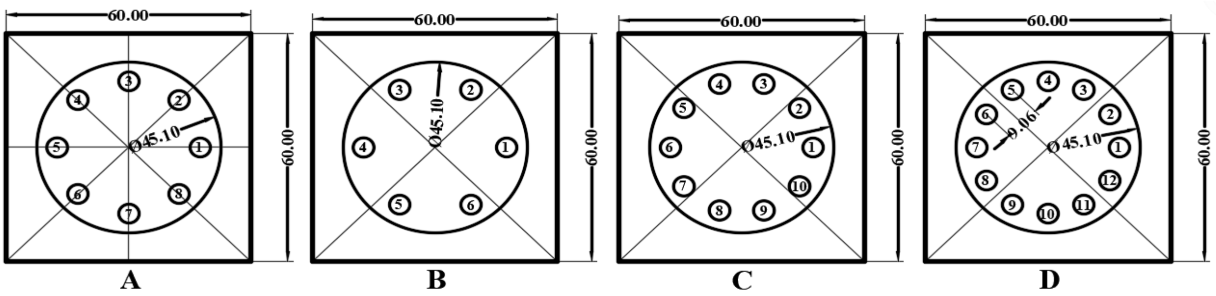

Figure 4 Geometrical positions of specimens in a circular plate.

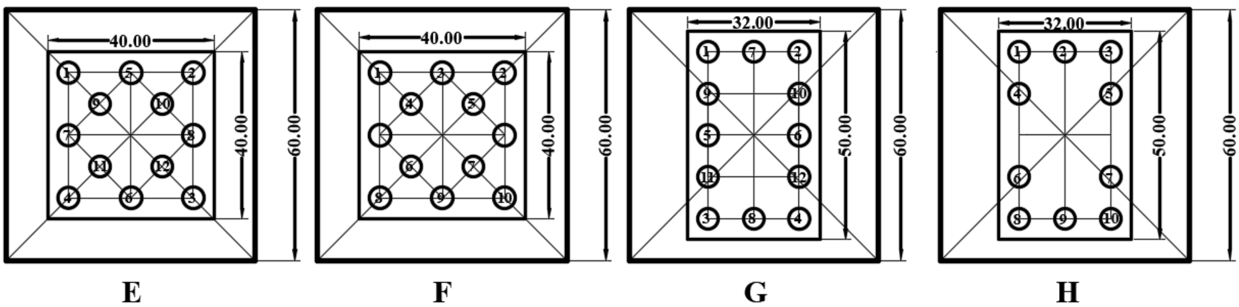

Figure 5 Geometrical positions of specimens in a square and rectangular plate.

In the 1st attempt rectangular plate was used as a foundation. The procedure discussed above was adopted and specimens were installed in the groups, 10 mm settlement was applied and resistance was measured at 0.5 mm intervals. In the 2nd and 3rd attempts circular and square plates were used as a foundation. Specimens were installed in the groups and a 10 mm settlement was applied, resistance was measured at 0.5 mm intervals.

Results and discussion

Preliminary and index test

The preliminary test demonstrates clay content of 65 %, liquid limit of 69 %, and higher value of plasticity index (48 %), low shear strength (6 kPa only). The tested soil is classified as high plastic clay (CH) according to the IS Soil Classification and the Unified Soil Classification System (USCS) also.

The sieve analysis test of corex slag particles shows an "S" type gradation curve that indicates well-graded sand. The specific gravity of the corex slag is 2.72, this value is nearer to the river sand particle available naturally. **Table 1** shows all the basic properties of soft soil, **Table 2** shows the primary test on corex slag and **Figure 6** shows the gradation curve of corex slag.

Table 1 Properties of soft soil.

No	Description	Value
01	Field moisture content	49 %
02	Specific gravity	2.53
03	Plastic limit	21 %
04	Liquid limit	69 %
05	Plasticity index	48 %
06	MDD with OMC	16.8 kN/m^3 at 45 %
07	Unit weight	14.0 kN/m^3
08	I.S. Classification	CH
09	Cohesion by Vane shear Test	6 kN/m^2
10	Sand content	14 %
11	Silt content	21 %
12	Clay content	65 %

Table 2 Preliminary test results of corex slag.

No	Particular	Value
01	Unit weight	19.8 kN/m^3
02	Specific Gravity	2.72
03	D_{10}	0.09
04	D_{30}	0.32
05	D_{60}	0.55
06	C_u	6.11
07	C_c	2.06
08	I S classification	SW

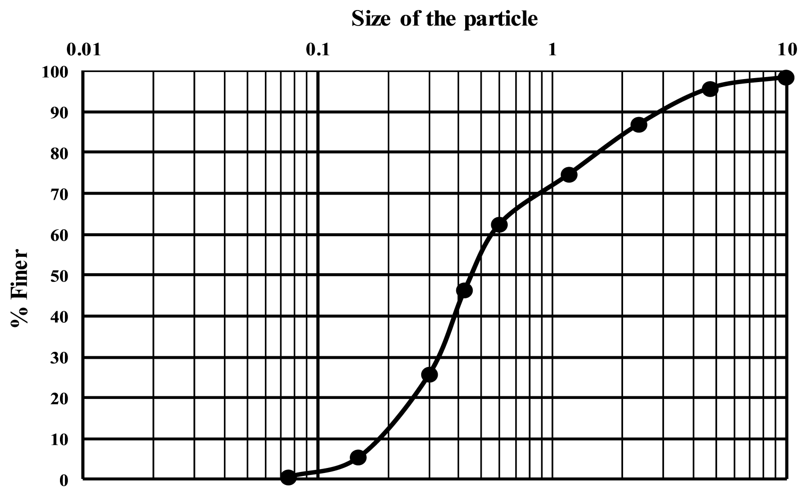

Figure 6 Sieve analysis of corex steel slag.

Compaction tests

Collected soft soil showed an MDD of 1.24 g/cm^3 at 20 % water content. When terrazyme is added to the clay, a reduction in adsorbed water was noticed. The key processes that improve the bonding between corex slag and soft soil are Bio-cementation and Bio clogging. Bio-clogging may be defined as the reduction or removal of pore space from the fine-grained soil. The bio-clogging effect is responsible for the reduction in porosity and hydraulic conductivity. While Bio-cementation is described as a cementation process that occurs due to microbial action in the presence of terrazyme. Bio-cementation creates stronger particle bonding resulting in higher MDD at lower OMC.

From all the compaction tests the optimum dosage of terrazyme was found to be 2 %. This dosage (2 % terrazyme) diluted in 10 and 12 % water content, gave MDD of 1.67 and 1.48 g/cm^3. Higher content (2.5 % terrazyme) diluted in 10 and 12 % water content, gave MDD of 1.62 and 1.40 g/cm^3.

Table 3 shows all compaction test results at different content of terrazyme diluted in water at various water contents.

Table 3 MDD at different water and terrazyme content.

No	Content of terrazyme	MDD (g/cm^3) at Different % of Water content							
		8 %	10 %	12 %	14 %	16 %	18 %	20 %	22 %
1	0.0 %	1.01	1.08	1.12	1.18	1.20	1.22	1.24	1.21
2	0.5 %	1.07	1.12	1.18	1.25	1.29	1.35	1.28	--
3	1.0 %	1.12	1.18	1.28	1.32	1.39	1.32	1.28	--
4	1.5 %	1.20	1.28	1.36	1.45	1.38	1.34	--	--
5	2.0 %	1.24	1.67	1.48	1.40	--	--	--	--
6	2.5 %	1.22	1.62	1.40	1.36	--	--	--	--
7	3.0 %	1.18	1.58	1.34	1.28	--	--	--	--

Unconfined compressive strength

A series of UCS tests were conducted on corex slag and terrazyme-treated clay to investigate the effects of terrazyme on strength performance at various curing periods. The UCS value at 21 and 28 days of curing for a proportion of 20 % of terrazyme treated clay and 80 % corex slag was found 56.19 and 60.95 kPa respectively. The mix proportion of 30 % of terrazyme treated clay and 70 % corex slag gave a UCS value of 93.90 and 103.75 kPa, at 21 and 28 days of curing. When 40 % of terrazyme treated clay mixed with 60 % of corex slag, UCS value of 152.98 and 169.64 kPa was obtained at 21 and 28 days of curing. While a blend of 50 % of terrazyme treated clay gave 161.4 and 184.21 kPa at 28 days of curing respectively. **Figure 7** shows the response of corex slag blended with terrazyme treated clay on UCS for curing periods ranging from 7, 14, 21 and 28 days. **Figure 7** also illustrates that as the terrazyme treated clay content rises, the UCS value increases. When 40 % terrazyme treated clay is blended with corex slag, the UCS value improves by 235 to 297 % when compared to 20 % terrazyme treated clay. At 50 % terrazyme treated clay mixed, there was a marginal increase in the range of 245 to 313 %.

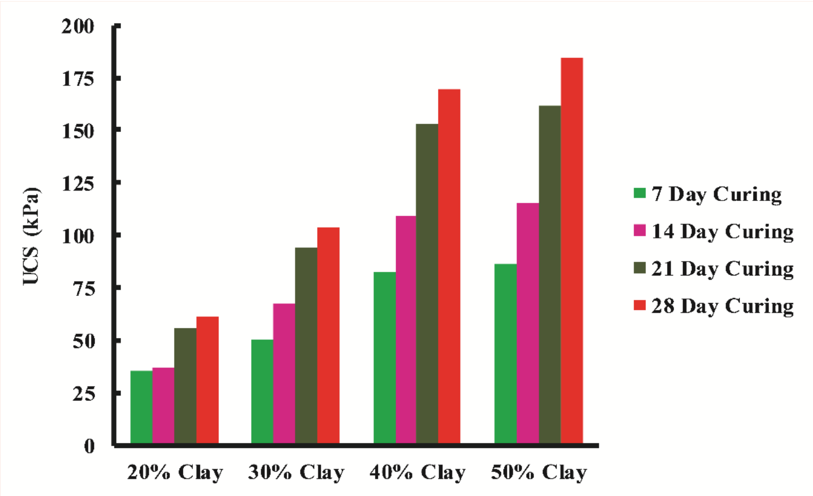

Figure 7 UCS test results at different clay content and curing period.

Application of specimens in group

A total of 18 laboratory plate load tests with rectangular, circular, and square footing with the nearly same area were performed. The load was applied to soft soil with and without corex slag and terrazyme-treated clay specimens. As expected it can be seen that increase in the numbers of the specimen results in an improvement in the load-carrying capacity of the soft soil. The test results also demonstrate the significant improvement of soft soil and 10 to 12 specimens are sufficient.

Unreinforced soft soil resisted 27.33 kPa pressure for a 10 mm settlement when a rectangular plate was used as a foundation and 129.32 and 135.75 kPa pressure was resisted when reinforced with 10 and 12 specimens at 10 mm settlement respectively. Circular plate resisted 29.95 kPa pressure for unreinforced soft soil, when reinforced with 10 and 12 specimens 142.90 kPa and, 147.63 kPa pressure were resisted at 10 mm settlement. Square plate resisted 30.79 kPa pressure for unreinforced soft soil, when reinforced with 10 and 12 specimens 148.61 and 157.32 kPa pressure were resisted at 10 mm settlement. Rectangular plate resisted 4.92 times higher load than virgin soil, while circular and square plate resisted 4.96 and 5.10 times higher. **Figures 8 - 10** show pressure-settlement responses for rectangular, circular and square plates. **Figure 11** shows a comparison of all 3 footings.

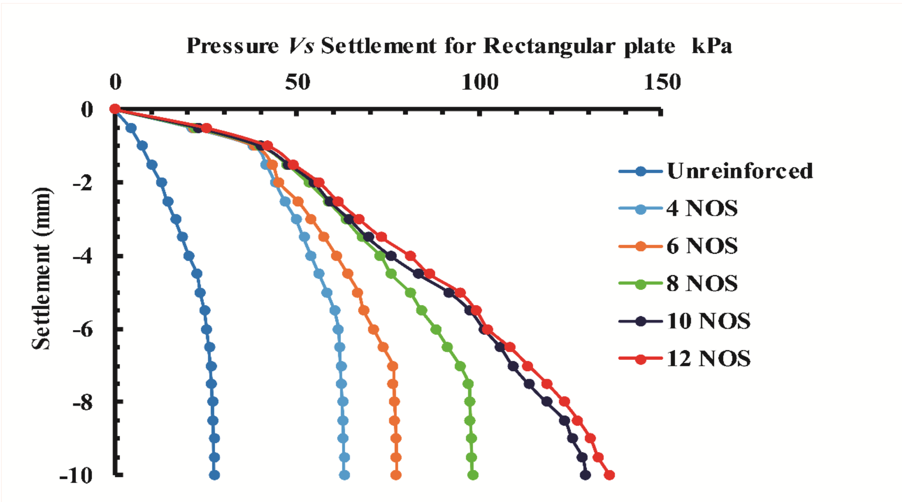

Figure 8 Pressure vs settlement curve for rectangular plate.

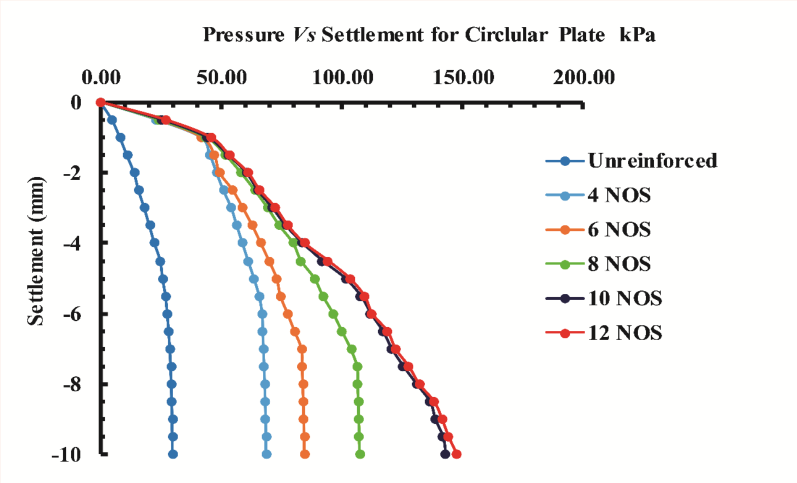

Figure 9 Pressure vs settlement curve for circular plate.

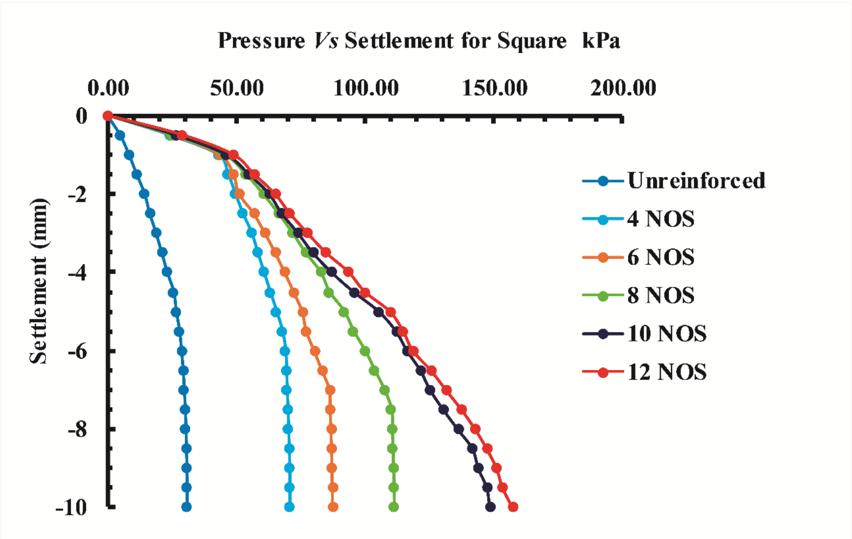

Figure 10 Pressure vs settlement curve for square plate.

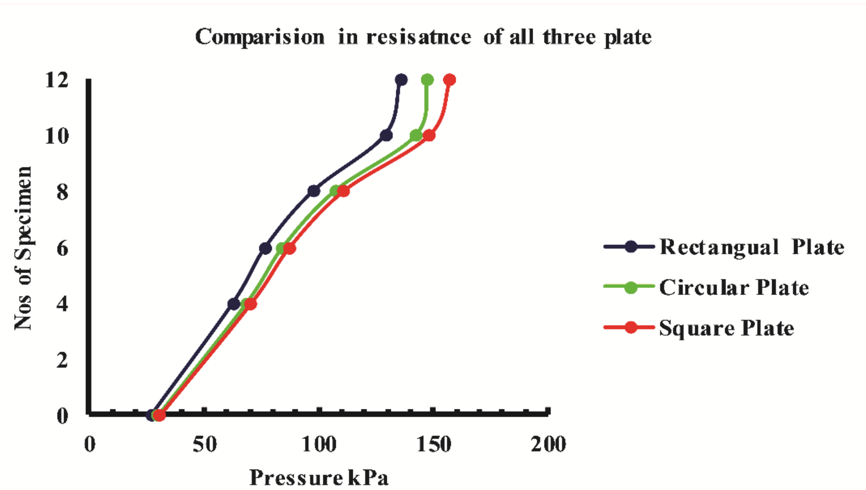

Figure 11 Comparison of resistance for all 3 footings.

Conclusions

A series of experiments were performed to determine the effect of terrazyme treated clay with corex slag. An effort was made to assess the proportions between corex slag and terrazyme treated clay through unconfined compression tests. The paper describes a new technique to stabilize the soft soil. The major findings from the results of the experiments are summarized as under:

1) Corex slag is a granular material available in sand-size particles, with the cementitious property that can be applied as a replacement for natural sand.

2) Terrazyme is a biodegradable organic liquid that can be utilized as a binding agent with clay content. Terrazyme treated clay reduces compacting effort and improves the MDD at lower OMC.

3) The blend of corex slag and terrazyme treated clay increases the stiffness which resists higher load with a reduction in deformation. The UCS value of the corex slag increases with an increase in the content of terrazyme treated clay, and the increase is about 235 to 245 % higher than the strength at 20 % terrazyme treated clay at 7 days curing period. The effect of the curing periods is also significant as UCS value enhances by 180 % at 28 days of curing that of 7 days curing.

4) Reinforcing soft soil by corex slag combined with terrazyme treated clay improves the load-carrying capacity of the footings. The number of the specimen is the major parameter affecting the behavior of rigid footing resting on soft soil. With an increase in the number of specimens, measurable improvement in load-carrying capacity is noticed.

5) All 3 footings demonstrate significant improvement up to 10 numbers of specimens. Marginal improvement is noticed at 12 number of specimens. One thousand six hundred cm^2 area can be replaced with 12 specimens of 5 cm diameter with an L/D ratio of 2. Square plate (footing) bears the highest load compared to rectangular and circular plates (footings).

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