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Technical note

Laboratory model studies on unreinforced and geogrid-reinforced sand bed over stone column-improved soft clay

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ABSTRACT

Results from a series of laboratory model tests on unreinforced and geogrid-reinforced sand bed resting on stone column-improved soft clay have been presented. The diameter of stone column and footing has been taken as 50 mm and 100 mm, respectively for all the model tests carried out. Load was applied to the soil bed through the footing until the total settlement reached at least 20% of footing diameter. As compared to unimproved soft clay, the increase in load-carrying capacity under different improved ground conditions has been observed. Influences of the thickness of unreinforced as well as geogrid-reinforced sand bed and the size of geogrid reinforcement on the performance of stone column-improved soft clay bed have also been investigated. Significant improvement in load-carrying capacity of soft soil is observed due to the placement of sand bed over stone column-improved soft clay. The inclusion of geogrid layer within sand bed further increases the load-carrying capacity and decreases the settlement of the soil. Due to the placement of sand bed, the bulge diameter of stone column reduces while the depth of bulge increases. Further reduction in the bulge diameter and increase in bulge depth are observed due to application of geogrid layer. The optimum thickness of unreinforced sand bed is twice the optimum thickness of geogrid-reinforced sand bed. Under specific material properties and test conditions, it is further observed that the optimum diameter of geogrid layer is thrice the diameter of footing.

1. Introduction

Stone column, one of the most commonly used soil improvement technique, has been utilized worldwide to increase the bearing capacity of soft soils and reduce the settlement of superstructures constructed on them. Several researches have been carried out to study the behaviour of stone column-reinforced ground over the past three decades (Madhav and Vitkar, 1978; Balaam and Booker, 1981; Alamgir et al., 1996; Poorooshasb and Meyerhof, 1997; Lee and Pande, 1998; Muir-Wood et al., 2000; Ambily and Gandhi, 2007; Elshazly et al., 2007; Krishna et al., 2007; Black et al., 2007; Madhav et al., 2008; Bouassida et al., 2009). Horizontal geosynthetic reinforcement sheets can be used in the granular columns to increase the load-carrying capacity as well as decrease the bulging of the columns (Madhav et al., 1994; Sharma et al., 2004; Wu and Hong, 2008). Geosynthetic encasement can also be used to extend the use of stone columns for extremely soft soil condition (Murugesan and Rajagopal, 2006; Murugesan and Rajagopal, 2007; Gniel and Bouazza, 2009; Wu and Hong, 2009; Lo et al., 2010).

A granular layer of sand or gravel, 0.3 m or more in thickness, is usually placed over the top of the stone columns to provide a drainage path and distribute the stresses coming from the superstructures (Mitchell, 1981). Shahu et al. (2000) developed a simple theoretical approach to analyze the granular pile-reinforced soft ground with granular mat placed on the top. Deb (2008) developed a mechanical model for predicting the behaviour of stone column-improved soft ground with granular bed placed over the stone columns. It has been observed that the presence of granular bed on top of stone column-reinforced ground reduces the stress concentration near top of the columns. The granular bed also helps to reduce the maximum as well as differential settlement and increase the load-carrying capacity of the stone column-improved soft soil.

The granular bed can be further reinforced with geogrid to enhance the load-carrying capacity and reduce the settlement of the stone column-improved soft clay. Han and Gabr (2002) performed a numerical analysis of geosynthetic-reinforced and pile-supported

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earth platforms over soft soil. Based on lumped parameter modelling approach, models have been developed for single layer (Deb et al., 2007) and multilayer (Deb et al., 2008) geosynthetic-reinforced granular bed resting on stone column-improved soft soil.

It has been observed that many analytical or numerical studies have been carried out to study the effect of unreinforced and geogrid-reinforced granular bed on settlement and bearing capacity of stone column-improved soft soil. Very limited experimental investigations have been conducted on this topic. In the present study, laboratory model tests have been conducted on single-stone column to study the effect of reinforcement diameter and thickness of reinforced as well as unreinforced sand bed on settlement response, bearing capacity and bulging of the stone column. The optimum thickness of the reinforced and unreinforced sand bed has also been determined.

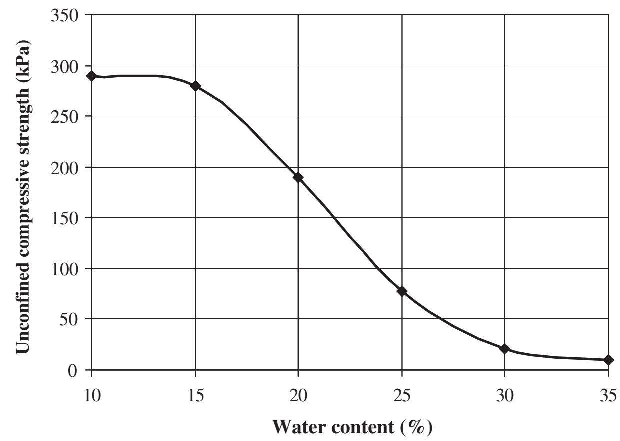

Fig. 1. Variation of unconfined compressive strength of clay with water content.

2. Experimental investigation

2.1. Material used

Clay, sand, stone and geogrid were used for the experimental investigations. The properties of clay have been presented in Table 1. Unconfined compressive strength (UCS) tests were carried out on clay samples at different water content and the variation of UCS of the clay with water content has been presented in Fig. 1. Water content of the clay was maintained at 30% throughout the series of tests and the corresponding UCS value of the clay (19 kPa) has been determined from Fig. 1. The bulk unit weight of the clay at 30% water content was determined to maintain identical unit weight in all the tests. Sand particles passing through 4.75 mm sieve were used to prepare the sand bed placed over the stone column-improved soft clay. Crushed stone materials of size 2 mm–6 mm were chosen to prepare the stone column. The properties of sand and crushed stone materials have also been presented in Table 2. From the particle size distribution curves of sand and stone column materials (as shown in Fig. 2), the uniformity coefficient, C_u and the coefficient of curvature, C_c values have been determined and presented in Table 2. Biaxial geogrid, made of high-density polyethylene, was used as a reinforcement layer. The properties of geogrid reinforcement have been presented in Table 3.

2.2. Experimental setup

To prepare the soft soil bed, a square tank of 525 mm × 525 mm size and 400 mm high was used in all the tests. A 50 mm diameter auger was used to dig the circular hole for preparing the stone column. Steel pipe of diameter 50 mm was used to finish the internal surface of the hole made by auger before filling it with stones. The stone column was installed up to the end of clay bed. Compactors with different sizes and weights were used to compact the clay, stones and sand to achieve the required density of the materials. Drilling guide was used to support the auger and place it vertical during drilling of hole in clay bed. Steel circular plate of diameter 100 mm and thickness 12.5 mm was used as footing to apply the load. Three arms were attached with the footing to fix up the dial gauges for measuring the settlement of footing during the application of load. Mechanical jack-frame arrangement was used to apply load on the soil stratum through the footing plate (as shown in Fig. 3). The load was applied through plunger and proving ring of 7.5 kN capacity. Three dial gauges were fixed at 120° angles to each other. The diameter of stone column was chosen to be 50 mm in all the tests and the depth of clay bed was maintained at 300 mm. The first test was carried out on clay bed without any improvement techniques and the load-settlement behaviour was investigated. Thereafter, other tests were carried out on soft soil improved by stone column alone and on soft soil improved by stone column along with unreinforced and geogrid-reinforced sand bed. Summary of the tests conducted has been presented in Table 4. Fig. 3 shows the schematic diagram of the experimental setup.

2.3. Preparation of clay bed

In all the tests, identical technique was adopted to prepare the clay bed. To maintain similar properties throughout the tests, clay bed was prepared at 30% water content in all the cases. The bulk unit weight at 30% water content was found as 19.8 kN/m^3. Before filling the tank with clay, polythene sheet was laid on internal walls of the tank to avoid any friction between clay and walls of tank and to prevent loss of water. To maintain same unit weight of clay in each test, the tank was filled in six equal layers of 50 mm thickness and the required weight of clay in each layer was calculated based on bulk unit weight of 19.8 kN/m^3. Each layer was compacted with steel rammers of diameter 45 mm, 70 mm, and square hammer of 150 mm × 150 mm to achieve the required thickness. Smaller

Table 1
Properties of clay.

Parameters	Value
Specific gravity	2.57
Liquid limit (%)	43.3
Plastic limit (%)	19.5
Plasticity index	23.8
Optimum moisture content (%)	18.3
Maximum dry unit weight	16.7 kN/m^3
Bulk unit weight at 30% water content	19.8 kN/m^3
Undrained cohesion	9.5 kPa
Compression Index	0.244
Classification based on plasticity characteristics (USCS)	CL

Table 2
Properties of sand and stone.

Parameters	Values	
	Sand	Stone
Specific gravity	2.75	2.70
Maximum dry unit weight	19.8 kN/m^3	17.2 kN/m^3
Minimum dry unit weight	16.17 kN/m^3	15.1 kN/m^3
Internal friction angle (ϕ) at 70% relative density	42°	45°
Bulk unit weight at 70% relative density	18.55 kN/m^3	16.5 kN/m^3
Uniformity coefficient (C_u)	3.6	2.1
Coefficient of curvature (C_c)	0.63	0.96