Behaviour of Geosynthetic Encased Crushed Construction and Demolition Debris Stone Columns

Divya, P.V.,¹ and Neethu, R.M²

¹P.V. Divya, Assistant Professor, Civil Engg, IIT Palakkad; e-mail: divya.pv.nair@gmail.com
²R.M. Neethu, Former undergraduate student; e-mail: neethu@gmail.com

ABSTRACT

Geosynthetic encased stone columns have been widely recognized as an efficient and cost-effective ground improvement technique for improving the load carrying capacity of soft soils. But, the conventional resources such as stone aggregates, gravel etc. are not able to cope with the high demand in the construction industry. Therefore, utilization of potential waste materials such as crushed construction and demolition debris (CCD) in lieu of conventional aggregates in stone columns is a viable and sustainable option. Hence, an attempt was made to use geosynthetics encased CCD columns in improving the load capacity of soft clayey soil. A series of load tests were carried out to examine the performance of soft clay reinforced with geosynthetic encased CCD columns. From the load tests conducted for various L/D (length of geosynthetic encasement to diameter) ratios of the stone columns, it was observed that with fully encased CCD columns, there is a maximum of about 6 fold increase in the load carrying capacity. Thus, CCD can be considered to be a good alternative for aggregates in geosynthetics encased stone columns.

INTRODUCTION

Rapid urbanization and growth of infrastructure in the present days has resulted in dramatically increased demand for land space. This necessitated the building industry to improve the soft soil grounds which otherwise are unsuitable for construction activities. When a project encounters difficult site conditions, one viable approach is to use various ground improvement techniques. It is widely recognized that provision stone columns is an efficient and cost-effective ground improvement technique for improving the load carrying capacity of weak soils. The improvement in load carrying capacity is mainly due to their higher strength and stiffness. In addition to it, they can accelerate the consolidation of clay soils by providing a preferential drainage path due to their higher permeability compared to the surrounding soil. In design of pile foundations, all loads are carried by piles and surrounding soils do not share any load. Different from pile foundations, columns and soils, which form a composite foundation, share the applied loads and deform together.

Subsurface soils whose undrained shear strength range from 7 to 50 kpa or loose sandy soils including silty or clayey sands represent a potential class of soils that can be improved by stone columns. (IS 15284 - Part 1: 2003). The lateral confinement provided by the surrounding soil is important for the mobilization of the strength. Owing to the low bearing capacity and high compressibility, soft clay soils are always a great challenge to geotechnical engineers. In such
soft clay soils with undrained shear strength less than 15 kN/m$^2$, provision of geosynthetic encasement is beneficial to provide lateral confinement since it helps easier installation, increase in load carrying capacity and stiffness and increase in shear load carrying capacity (Murugesan and Rajagopal 2008).

Well graded crushed stone or gravel of size 20 mm to 75 mm are generally used in stone columns. The crushed stone or gravel used in stone columns should be inert, chemically stable, of proper gradation, free-draining, hard, and capable of making stone columns with relatively high friction angle (IS 15284 - Part 1: 2003; Serridge 2005). It must also comply with acceptable criteria in terms of material type, grading, hardness, particle shape, flakiness and chemical stability. But, the conventional resources such as stone aggregates, gravel etc. are not able to cope with the high demand in the construction industry.

Disposal of waste in an environmentally sound manner is the need of the hour at global, regional and local levels. In India, according to solid waste management rules (SWM Rules 2016), every effort shall be made to recycle or reuse the potential waste materials to achieve the desired objective of zero waste going in to the landfill. Some of the waste products have favourable geotechnical properties to be bulk utilized in various geotechnical applications such as a fill material in reinforced soil structures and in embankments, etc. Construction and demolition debris is generated out of construction and demolition of buildings and other infrastructures and it comprise of building materials, debris and rubble resulting from construction, re-modeling, repair and demolition of any civil structure (C&D rules, 2016). It can be crushed and processed to produce a waste of relatively homogeneous particle size in gravel size range. In India, being a relatively new concept, only less than 5% of the construction and demolition waste generated is processed; though lots of initiative is taken by the Government of India to set up the processing plants very recently (CPCB, 2017). Few researchers have reported that the CCD materials found to have geotechnical and hydraulic properties comparable to that of typical granular materials used in various geotechnical construction (Santos et al. 2014; Vieira et.al. 2015). Hence, in the present study, an initial investigation on the utilization of potential waste materials such as crushed construction and demolition debris (CCD) in lieu of conventional aggregates in stone columns is attempted as a viable and sustainable option to improve the load capacity of soft clayey soil.

**MATERIALS AND METHODS**

The soil was obtained from a nearby excavation site at Chennai, India. The air dried and pulverised soil was sieved through 4.75 mm. Basic index tests were carried out on the soil. The specific gravity of soil was 2.56. The maximum dry density and optimum moisture content of the soil was 15.5 kN/m$^3$ and 20% respectively. The soil was classified as clay of high compressibility CH according to unified soil classification system. The undrained shear strength of the clay at a water content of 30% was found to be 14 kN/m$^2$. The geosynthetics used in the present study was a commercially available polypropylene nonwoven geotextile. The ultimate tensile strength of geosynthetic was 9 kN/m; thickness was 1 mm and mass per unit area was 140 g/sq.m.

The construction and demolition waste for making stone columns was collected locally. The composition of waste can have high variability based on the location of collection. However, for the bulk utilization of the waste in various geotechnical applications, this could be done from the local processing plant for the construction and demolition waste. In the present
study, the construction and demolition waste which mainly included the crushed waste concrete cubes, construction and building repair waste etc. was crushed and then sieved to obtain particles of size between 2 to 10 mm. The grain size distribution of clay and CCD used in the present study is shown in Fig. 1. The specific gravity of the CCD (selected portion of the collected construction and demolition waste) was found to be 2.61. The maximum dry density as obtained from relative density test was found to be 16.83 kN/m$^3$. The angle of internal friction of the CCD as obtained by direct shear test at the corresponding density was obtained as 32°.

![Grain size distribution curve of Clay and CCD used in the present study](image)

An experimental investigation was carried out in the present study on single geosynthetic encased CCD columns installed in soft clay. A unit cell test tank was fabricated for the purpose of conducting load tests, as per the unit cell concept. Similar methods of load tests on stone columns were earlier reported by Murugesan and Rajagopal (2008) and Ambili and Gandhi (2007). Unit cell, which consists of one column and its surrounding soil, is often used to analyze a column-reinforced soft foundation. Since the unit cell is symmetric by geometry a uniform load evenly distributed over the infinitely extended area and applied by a rigid raft will not cause any shear stresses or horizontal deformations to develop at its outside boundaries. According to unit cell concept, the plan area of the unit cell tank is equivalent to a typical unit cell area of stone columns. Here, the diameter of the tank adopted was 210 mm equivalent to a typical unit cell area of CCD columns. The height of the tank was 520 mm. The diameter and height of the CCD column is maintained as 500 mm and 50 mm. The geosynthetic was stitched to form the encasement around the CCD columns. Figure 2 shows the schematic of the load test set up used in the present study.

The clay bed was prepared at a water content of 30% corresponding to an undrained strength of 14 kN/m$^2$. A replacement technique was used to construct the column. In this technique, open ended steel pipe of 50 mm diameter and 1 mm wall thickness was pushed inside...
the clay bed exactly at the center to reach the bottom of the clay bed. A helical steel auger was used to make a hole/replace the soil for the CCD column construction in the clay. The geotextile of required length and diameter is then placed inside the cavity thus formed and CCD are then poured into this hole and compacted as the steel pipe is removed. It is compacted using a tamping road to the required density. Density was maintained as 16.5 kN/m$^3$ for all the tests reported in the present study. The other possible method of installation is the displacement technique wherein a closed end mandrel is inserted into clay bed to create holes for the CCD columns. But this method may creates disturbances in the prepared clay bed.

![Figure 2. Schematic of the load test up on geosynthetic encased CCD columns](image)

Once the clay bed and CCD columns are prepared, a sand pad of about 10 mm thickness was placed on the top and subjected to vertical loading. The load was applied using a steel plate of 10 mm thickness at a constant displacement rate of 1.25 mm/min. The load and settlement values were noted at different intervals. In the present study, tests were conducted by applying load on the unit cell area as shown in Fig. 2. Loading applied on the stone column area can give an indication of limiting load capacity of the individual stone columns and the mobilization of the strength from the lateral confinement (Murugesan and Rajagopal, 2008; Ambili and Gandhi, 2007).
RESULTS AND DISCUSSIONS

The load-displacement behaviour of the clay treated with CCD columns were determined up to a settlement of about 25 mm. The variation of settlement with stress for unreinforced clay bed is shown in Figure 3.

![Figure 3. Variation of settlement with stress for unreinforced clay bed](image)

It was observed that the load carrying capacity of the soil is low, of about 23 kN/m². This is also evident from the bulging and squeezing out of soil from the sides during the test. The tests were done for full encasement and partial encasement. The encasement length (L) to diameter of the CCD column (D) ratio is varied as 5 and 10. The settlement versus stress curves for geosynthetic encased CCD columns are shown in Fig. 4. Figure 4 indicates that there is an increase in load carrying capacity of clay reinforced with CCD columns with L/D ratio of 10 compared to L/D ratio of 5, though not very significant. However there is a significant improvement in the load carrying capacity of geosynthetic encased CCD columns compared to unreinforced clay as shown in Figure 3 and 4.

In the case of partially encased column, a slight reduction in load capacity takes place after a settlement of about 5 mm, compared to full depth encasement. This could be due to the dilation effect of CCD columns owing to the bulge formation underneath. Once the bulge has formed, it mobilizes the strength and enhanced bearing capacity is achieved. This behaviour is comparable with the behaviour of conventional stone columns as reported by Murugesan and Rajagopal (2008).
Further, in order to visualize the failure pattern of the stone columns during the load tests, Plaster of Paris was poured into the CCD column at the end of the test. This material in the powder form was mixed with water, to form a thick paste which cannot penetrate into the soil due to high viscosity and eventually gets hardened into a solid within the CCD stone column. Once it gets hardened, the CCD column was carefully removed from the test tank and surrounding soil.

Figure 5 indicate the photograph taken on the exhumed fully encased CCD column. As can be seen from the photograph, slight bulging is there on the initial top portion of the CCD columns. The stress transfer in a flexible stone column is dominated by lateral confinement. Near the ground surface, since the overburden stress and the confining stress are low, the flexible column will bulge within a certain depth. As a result, the deeper portion of the column may not provide much resistance to the applied load. However, in the present study, due to encasement, it did not undergo much bulging. The strain in the geosynthetic encasement can be measured if strain gauges are attached to the geosynthetic encasement, though not covered in the present paper.
CONCLUSIONS

The present study indicate the potential of the utilization of crushed construction and demolition debris (CCD) in lieu of conventional aggregates in stone columns as a viable and sustainable option to improve the load capacity of soft clayey soil. The load carrying capacity of the clay soil was improved by geosynthetic encased CCD stone columns. From the load tests conducted for various L/D ratios (length of geosynthetic encasement to diameter) of the stone columns, it was observed that with fully encased CCD columns, there is a maximum of about 6 fold increase in the load carrying capacity. There is an increase in load carrying capacity of fully encased CCD column (with L/D ratio of 10) compared to partially encased CCD column (with L/D ratio of 5); though not very significant. In the case of partially encased column, a slight reduction in load capacity takes place after a settlement of about 5 mm, compared to full depth encasement. This could be due to the dilation effect of CCD columns owing to the bulge formation underneath. Once the bulge has formed, it mobilizes the strength and enhanced bearing capacity is achieved.

However, further work in this direction are warranted by varying the elastic modulus of the geosynthetic encasement, measurement of hoop strain developed and compressibility behaviour of geosynthetic encasement. Also, complete physical, chemical and geotechnical
characterization of the construction and demolition waste has to be done in addition to its long-term stability; to comply with acceptable criteria to be used as a replacement of conventional aggregates in stone columns.

REFERENCES


