STABILISATION OF SOFT CLAYS USING GEOSYNTHETIC ENCASED STONE COLUMNS WITH VACUUM APPLICATION

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ABSTRACT

Stone columns are often considered as an excellent ground improvement technique adopted to improve the load carrying capacity and reduces the settlement characteristics. However the load carrying capacity mainly depends on the undrained shear strength of surrounding soils. Reinforcement in the form of encasement is usually provided around the stone columns which imparts lateral confinement, resulted in improved load carrying capacity. This geosynthetic encasement also acts as an excellent filter, prevents the entry of finer clay particles and offers better drainage path for pore water dissipation. Vacuum consolidation is a type of preconsolidation technique in which vacuum is applied through PVD's in a sealed membrane system. The applied vacuum creates negative pore pressure which increases the effective stress without altering the total stresses. The improvement in effective stress thus leads to increase in undrained shear strength of clay soils. The research work involves application of vacuum through encased stone columns and tests done to study the improvement in load carrying capacity of encased stone column after vacuum application. Soil samples after the vacuum consolidation were also taken to study the increase in undrained shear strength after vacuum application.

Keywords: Ground improvement, soft soils, encased stone column and vacuum consolidation

INTRODUCTION

Due to the rapid increase in population and its consequent pressures on land availability, use of marginal lands is inevitable for large-scale industrial and infrastructure development projects. These soft clay soils have low bearing capacity and high compressibility characteristics. In order to overcome these limitations, ground improvement techniques are commonly utilized. The ground improvement technique involves either mechanical modification, physical, chemical modification or hydraulic modification.

Construction of stone columns is a soil reinforcement technique which improves bearing capacity and reduces settlement characteristics. The load carrying capacity of the stone columns, apart from other factors, mainly depends on the lateral confinement from the surrounding soil. There are many reports which highlight the failure of stone columns due to inadequate confinement offered by the surrounding soft clay soils (example McKenna *et al*. 1975). This limitation can be overcome by encasing the stone column with geosynthetics, which offers lateral confinement to the stone column and makes them to behave like a semi rigid pile. It was also observed that provision of geosynthetic encasement prevents the entry of surrounding clay soil in addition to providing effective drainage path. The spacing of the stone columns for a given load intensity depends, to a large extent on the undrained shear strength of the surrounding soil, because stiffer soils provides better confinement. For very soft clays, the stone columns need to be installed at very closer intervals with area replacement ratios often exceeding 25% making the stone column treatment highly expensive.

In order to reduce the area replacement ratio of stone columns, possibility of improving the undrained shear strength of the surrounding soil is to be attempted. Vacuum consolidation technique is a type of ground improvement technique which employs application of vacuum through vertical drains in a sealed membrane system. Application of vacuum removes atmospheric pressure inside the soil effectively so that the negative pore water pressure develops inside the soil grains thus increasing the effective stress without altering the total stress. With the increase in effective stress, application of vacuum pressure results in improvement in undrained shear strength within a short treatment duration. It was reported that the bearing capacity of the ground may often gets doubled after vacuum consolidation.

In the present study, it is attempted to improve the shear strength of the clay surrounding the encased stone column by adopting vacuum consolidation technique. Unit cell experiments were conducted in the laboratory using soft clay, to study the effect of applying vacuum through the encased stone column. Improvements in the undrained shear strength and time-settlement data were monitored. Load tests on the stone column after the application of vacuum pressure indicates considerable improvement in the capacity suggesting that the proposed method is a viable ground improvement technique.

LITERATURE REVIEW

Usually granular columns in the form of stone columns or sand compaction piles provide increased load carrying capacity, with increased stiffness resulting in reduced settlements (Greenwood 1970). Also, the lateral resistance offered by the surrounding soil is found to be equivalent to that of passive resistance mobilized behind the retaining wall which is laterally translated to the soil (Wong 1975). In a stone column improved ground, each stone column influences a certain area around the stone column area called Unit cell. In order to study the behavior of stone columns, laboratory scale model studies are widely carried out, in the literature, using unit cell approach. In order to improve the load carrying of stone columns in very soft ground, the possibility of encasing the stone columns with geosynthetics was employed in the literature (Van Impe and Silence 1986, Murugesan and Rajagopal, 2006). Van Impe and Silence (1986) validated the analytical solutions using the experimental results on stone columns with geosynthetic encasement. Tests on geosynthetic encased stone column under field conditions shows improvement in load carrying capacity with geosynthetic encasement (Trunk et al. 2004). Laboratory scale studies also shows that use of geosynthetic encasement offers lateral confinement and prevents, lateral squeezing of stones on the surrounding soft clays (Murugesan and Rajagopal 2006).

The concept of vacuum consolidation of clay soils for ground improvement was first proposed by Kjellman (1952). In this method the effective stress in the soil mass is increased by the application of vacuum in a closed system. The reduction of the pressure in the soil below the atmospheric pressure in the confined soil mass leads to an equal increase of all round effective stresses. This leads to an increase in the effective stress without any increase of total stresses. The increase in effective stress cause consolidation of soil resulting in reduction in water content that leads to increase in shear strength. The principle and mechanism of vacuum preloading have been discussed by several researchers in the published literature (Chu et al. 2000, Chai et al. 2005, Chu and Yan 2005). It was observed that there is an improvement in shear strength after vacuum application when compared to that of the equivalent surcharge loading. The method has been widely adopted in South East Asian countries for land reclamation and soil improvement works since 1980 (Qian et al. 1992; Chu et al. 2000; Tang and Shang 2000). Compared with the fill surcharge method for the equivalent load, the vacuum preloading method is reported to be more economical and faster (Chu et al. 2000 and Yan and Chu 2003). Vacuum consolidation method can be combined with surcharge loading (especially by impoundment of water) to increase the loading intensities (Lin et al. 2003). The practical effects of the vacuum consolidation have been discussed by Qian et al. (1992), Chu et al. (2000), and Indraratna et al. (2005).

In the present work, an attempt is made to increase the undrained shear strength of the surrounding soil by the application of vacuum through the encased stone column so as to increase the load carrying capacity of the stone column. The method utilizes the advantage of the drainage path created by the stone column installation.

MATERIAL SELECTED FOR THE STUDY

A fine grained silty clay soil obtained from the lake bed inside the IIT Madras campus, Chennai, India was used for the study. The liquid limit and plastic limit of the soil are 44% and 20% respectively. The soil has 20% of sand, 31% of silt size and 49% of clay sized particles. Angular stone chips of size 2 to 10 mm were used for the stone column. The geosynthetics used for encasing the stone column is a woven geotextile type with tensile strength of 80 kN/m.

Experimental Set Up and Testing Procedure

Usually stone columns are installed in triangular or square pattern in such a manner that each column influences certain area of soil, called unit cell. In the present experimental work unit cell experiments were carried out. Two unit cell set ups made of stainless steel tubes having inner diameter of 202 mm and height of 480 mm height were fabricated for the study. The inner surface of the cells was specially polished so that the friction between the soil and the wall is negligible. In addition Silicone grease is smeared over the surface to reduce the friction further. These cells have removable bottom plate through which the vacuum pressure can be applied. The set-up has provision for applying the

vacuum at the bottom through a vacuum trap and a regulator. The vacuum is generated using a dedicated vacuum pump.

Sample preparation

Clay soil obtained from the IIT Madras lake bed was initially soaked in water and mixed thoroughly using a stirrer at water content of about 1.5 times the liquid limit. The clay slurry thus produced was then carefully poured in to the steel tank of 202 mm diameter and 480 mm long, after smearing the inner surface of the cell with silicone grease so as to reduce the side wall friction. Care was taken to ensure that no air bubbles are entrapped in the clay slurry. The top and bottom of the cells were provided with geotextile filter as separators. The slurry was then allowed to consolidate by applying loads in stages to a maximum pressure of 10 kPa, using the pneumatic cylinder as shown in Fig. 1. Drainage was permitted at the top and bottom during the consolidation. The constant pressure was applied using dead weights. Time–settlement data were recorded continuously.

Fig. 1 Set-up used for consolidating the clay

Installation of encased stone column

Once the consolidation of soil gets over, installation of stone column is carried out. The stone columns in the current study was installed by displacement method using a casing pipe having an outer diameter equal to the diameter of the stone column (50 mm) and encasement was done by wrapping the geotextile around the casing pipe. The casing pipe with the geotextile was carefully pushed in to the consolidated clay in the unit cell vertically at the centre till it reaches the bottom of the unit cell. Only static force was used to push the casing pipe so as to minimize the disturbance in the clay soil. The displaced clay during the installation was taken out and the surface of the soil was trimmed to its original level.

The quantity of the stone aggregate required to form the stone column was measured a prior and charged in to the casing pipe in layers of 50 mm thickness. Before charging in to the casing pipe the stone aggregate was moistened in order to prevent it from absorbing the moisture from the surrounding clay. After placing each layer of stone aggregate, the casing pipe was lifted up gently to a height such that a minimum overlap of 15 mm between the bottom of the casing pipe and the stone fill within the casing pipe was always maintained. Immediately after lifting the casing pipe, the stone aggregate was compacted with a tamping rod (10 mm diameter and 1 meter long) with 25 blows falling from a height of 250 mm. Each layer of the aggregate was compacted using the same number of blows. A view of the sample after installation of the stone column is shown in Fig. 2.

Fig. 2 Encased stone column in the Unit cell

Application of vacuum through encased stone column

After the installation of encased stone column, the top of the clay soil surface with the stone column was carefully leveled and a rubber sheet of 220 mm diameter was placed on it. Two settlement plates were placed above the rubber sheet. The top of the clay surface is made air-tight by pouring bentonite slurry. The bottom of the stone column was connected to the vacuum pump through a vacuum chamber and a regulator. Required level vacuum pressure (65 kPa) can be applied on the soil through

the encased stone column for the consolidation to take place. During consolidation, time-settlement data was continuously monitored through dial gauges. The complete set-up is shown in Fig. 3.

Fig. 3 Complete experimental set-up

Once the consolidation settlements have reached a steady state, the vacuum application was terminated. The time taken for full consolidation is about 240 hours. The bentonite slurry and the rubber sheet from the top of the set up were removed and the strength of the stone column was determined by load tests.

Surcharge loading condition

In order to validate the load carrying capacity of stone columns after vacuum consolidation, tests were performed under surcharge loading conditions also. The method of preparation of clay bed and installation procedure for encased stone column is same as that discussed in the previous section. Loading plate having diameter equal to that of diameter of the unit cell was placed at the top of the specimen. Loading is done by means of pneumatic piston which transmits the load (65 kPa) to the plate which in turn distributed uniformly throughout the top surface of the unit cell. Like vacuum consolidation, in the surcharge loading also time-settlement response is recorded.

Load tests on encased stone column

After the application of corresponding pressure levels the encased stone columns were loaded so as to determine the load carrying capacity. The load tests were performed by applying uniform rate of deformation through steel plate (equal to the diameter of the stone column and two times the diameter of stone column) at a deformation rate of 1.25 mm per minute. The loads corresponding to the deformations were recorded during the test. Type of load tests performed during the experimental work includes the following tests:

i) Encased stone column without vacuum application and
ii) Encased stone column after vacuum application
iii) Encased stone column after surcharge loading

After the load tests, water content values were taken out at three locations i.e., top, middle and bottom to know the variation in water content with depth.

RESULTS AND DISCUSSIONS

Figure 4 shows the time-Settlement curve between surcharge loading and vacuum preloading. It can be seen that the rate of settlement by vacuum consolidation is faster compared to the surcharge preloading. In addition, the settlement in the case of vacuum application is considerably more than that of the surcharge preloading. The reason may be attributed the fact that the surcharge is applied on the top of soil with encased stone column. The load applied is partly taken by the stone column and partly by the soil. However, in the case of vacuum consolidation, the effective stress is increased to the soil through the pore phase. As the entire load is transferred to the soil mass, the settlement is more. This is further evaluated through the water content variation along the depth of the sample.

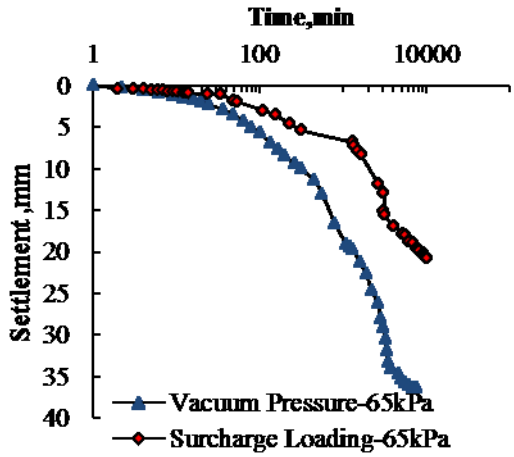

Fig. 4 Time – settlement plot for surcharge loading and vacuum loading.

As mentioned in the experimental programme, the water content values were taken on three locations i.e. top, middle and bottom of the unit cell. The values of water content obtained after surcharge and vacuum loading is given in Table.1. It is interesting to see that the water content values goes on increasing with depth during surcharge loading.

This confirms that load is not completely transferred to the soil. But in case of vacuum application, the water content values are found to be constant with depth. Further, the water content values are lower for the case of vacuum consolidation. The uniformity in water content values indicating that, the vacuum is spread uniformly throughout the entire depth and the negative pressure developed between the soil grains removes the pore water between the soil grains resulted in higher settlements.

Table 1 Comparison of water content after surcharge and vacuum loading

Position	Water content,%	
	65 kPa Surcharge loading	65 kPa vacuum loading
Top	41.71	39.31
Middle	45.12	39.41
Bottom	45.14	38.45

Figure 5 shows the comparison of load carrying capacity of the three cases. It is seen from the graph that the application of vacuum to the soil through the encased stone column increase the load carrying capacity by about two times. Compared to the surcharge loading, vacuum loading is more effective in terms of improvement is load carrying capacity. The reason may be attributed the load transfer mechanism explained earlier that the vacuum pressure is applied in the pore phase so that the entire effective stress is properly transferred to the soil. This results in more consolidation settlement with lesser water content, which in turn increases the undrained shear strength. Thus application of vacuum through the stone column improved ground can be viable ground improvement scheme that can be used to enhance the load carrying capacity of stone columns.

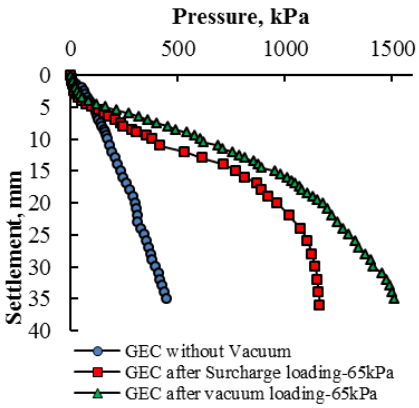

Fig. 5 Pressure -settlement curves for three systems

CONCLUSIONS

Based on the results of experiments conducted on the encased stone columns on soft clays, the following conclusions can be drawn:

(1) Compared to the vacuum consolidation on the stone column improved soil, the settlement obtained by surcharge preloading is less.

(2) The water content is uniform and is less compared to the surcharge preloading. For the case of surcharge preloading, the water content increases with depth. This is attributed to the load transferred to the stone column that prevents the full consolidation under the surcharge loading.

(3) The load carrying capacity of the stone column after vacuum consolidation is about two times that of the stone column without vacuum consolidation. This is due to the increase in undrained shear strength of the soil surrounding the stone column.

(4) Due to the transfer of load to the stone column under the surcharge preloading case, the load carrying capacity is less compared to vacuum preloading.

(5) Application of vacuum through the stone column improved ground can be viable ground improvement scheme that can be used to enhance the load carrying capacity of stone columns that results in increased column spacing.

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