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Use of geosynthetics in vibro stone columns

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ABSTRACT: Vibro stone columns are a common method of ground stabilisation. They improve the bearing capacity and reduce the settlement of foundations. The overall performance of the technique depends on several aspects such as the strength of the column material, strength of the surrounding clay, area replacement ratio and column length. A stronger *insitu* material will provide increased lateral confinement to the stone column. This paper examines the effect of placing a geo-grid around the column in order to further enhance the lateral confinement and therefore improve the overall performance of the vibro foundation. As part of the ongoing research, triaxial tests were carried out on reinforced and unreinforced sand columns which had been installed in clay samples (200 mm in length and 100 mm in diameter). The composite sand/clay specimens were loaded under undrained conditions and were subjected to two different loading conditions: uniform and foundation type (concentrated) loading. The test results indicate that the performance of the composite material can be improved by reinforcing the sand column with a geo-grid.

1 INTRODUCTION

In recent times increasing land prices, the limited availability of sites and the government initiative to redevelop inner cities has forced the building industry to look for cheaper land for construction. As a result construction is now being carried out on sites which, due to poor ground conditions, would not previously have been considered economic to develop. These types of land include brownfield sites, filled ground, land containing peat/organic deposits or land containing recently deposited alluvium. In recent years various ground improvement techniques have been employed in order to artificially improve the soil properties in these sites.

The primary requirement of any ground improvement technique is to improve the compressibility characteristics of the insitu soil and consequently reduce the expected foundation settlements. The most common methods available include vibro stone columns, piling, preloading and sand drains etc. This paper is concerned with vibro stone columns. Unlike cohesionless material, clayey soils are largely unaffected by induced vibrations and so their properties are not significantly improved by compaction alone. However when columns of densely compacted course granular backfill are installed during the compaction process there is a substantial improvement in the strength and settlement characteristics of the soft clay. Unlike piles, which transfer the surface loads to a stronger underlying stratum, bypassing the weak material, stone columns utilise the load carrying properties of the surrounding material (Fig. 1).

When load is applied, a stone column develops end bearing pressures and side friction stresses similar to a pile. However the stone column also bulges, so it requires lateral support from the surrounding soil (Fig. 1b) thus forming a composite soil/stone column system. The increase in the lateral stresses in the clay further leads to consolidation and subsequent relaxation of stresses. This process continues until equilibrium is reached. The soil confines the stone column and the passive resistance causes the granular column to reinforce the ground and improve bearing capacity and stiffness.

In the last three decades, the vibro stone column technique has become an environmentally acceptable and economically viable alternative to other conventional methods of ground improvement. A number of processes have been developed over the years for installing the columns; these include the wet and dry top-feed methods and the dry bottom-feed method (McKelvey & Sivakumar (2000), Hu (1995), Greenwood & Kirsch (1984), Barksdale & Bachus (1983), Hughes & Withers (1974)).

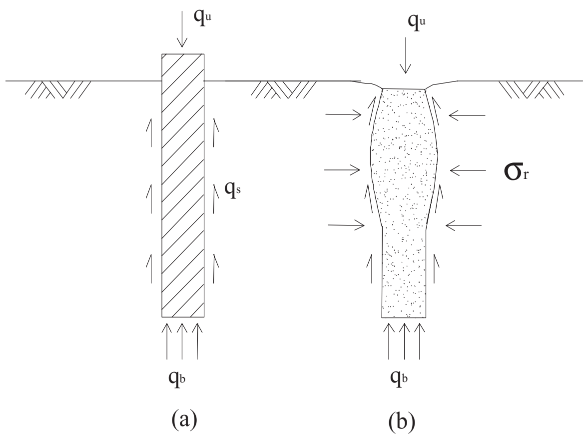
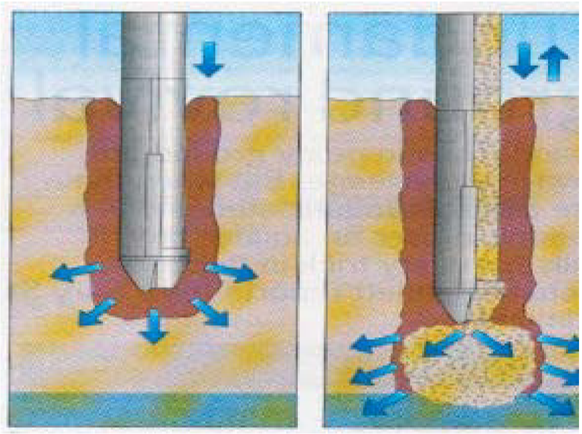


Figure 1. (a) Pile (b) Vibro stone column

The bottom-feed process (Fig. 2) is the most commonly used method in the UK since it is applicable to a wide range of site conditions and soil strengths. It is also unaffected by the



(a) (b)

Figure 2. Bottom feed method (a) Poker penetration and (b) stone discharge

presence of ground water. The modified bottom-feed vibrator incorporates an additional tremie pipe so that the granular material may be supplied internally to the nose of the poker. The stone is then discharged and compacted in lifts while the poker remains in the hole. This ensures stability throughout construction of the columns.

Vibro stone columns are suitable for supporting lightweight structures such as low-rise housing and industrial warehouses. They have been installed successfully in soils with undrained shear strengths (c_u) as low as 7 kPa, although the technique is not usually recommended where c_u is less than 15 kPa because of the low radial support provided to the columns. This paper investigates the effect of placing a geosynthetic material around the stone column in order to increase this lateral support and hence improve the load carrying capacity.

In an attempt to understand and predict the behaviour of ground reinforced by stone columns, many studies based on physical modelling, mathematical analysis and full scale testing have been carried out during the last three decades. Previous laboratory based research, carried out by Hughes & Withers (1974), Charles & Watts (1983), Bachus & Barksdale (1984) and Hu (1995), has been invaluable for establishing an understanding of the behaviour of stone columns. However, while many of these early studies were based on experiments carried out in one-dimensional loading chambers, this paper reports the performance of a stone column under triaxial loading.

2 EXPERIMENTAL WORK

The experimental work involved a series of triaxial tests on samples of kaolin clay in which columns of sand were installed. The kaolin was mixed at 1.5 times the liquid limit and consolidated under a vertical pressure of 200 kPa in a one-dimensional loading chamber, 100 mm in diameter and 500 mm deep (Fig. 3). When consolidation had completed, the pressure in the cylinder was reduced to zero under undrained conditions. The top cover was removed and a helical auger was used to bore out a 32 mm diameter hole while the sample remained in the loading chamber. A frozen sand column was then inserted into the empty borehole. The methods adopted for preparing the sand columns are outlined below.

Unreinforced columns: The sand, prepared at a water content of 18%, was compacted in layers into a tube (a thin plastic sheet rolled around the helical auger to give a 32 mm inner diameter). The filled tube was then left in a freezer for 24 hours. When it was taken out the tube was cut along its length and the sand column was removed. A photograph of the frozen column is

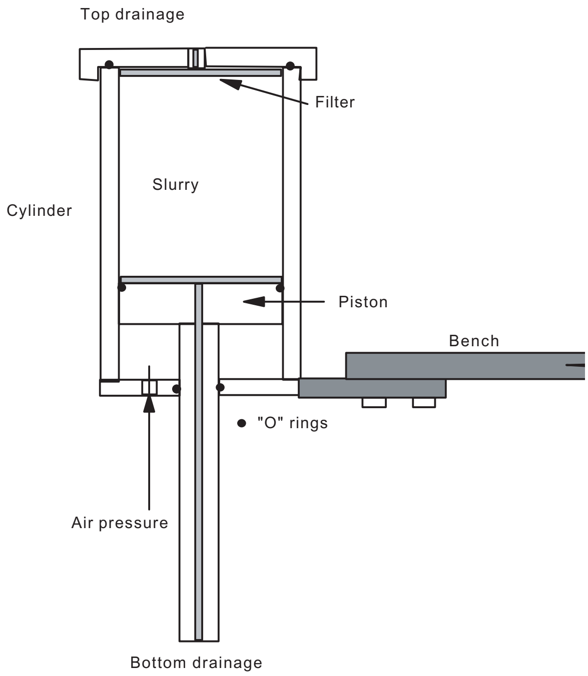


Figure 3. One-dimensional loading chamber

shown in Figure 4a. The sand was dyed blue using waterproof ink so as to differentiate the column of sand from the surrounding clay.

Reinforced columns: For the reinforced columns, a sleeve made from a geosynthetic sheet was placed inside the plastic tube. Both were then rolled around the helical auger to give a 32 mm inner diameter. The sand, again prepared at a water content of 18%, was compacted in layers into the tube. After freezing, the plastic tube was cut along its length to remove the frozen, geosynthetic-covered sand column. A photograph of the reinforced column is shown in Figure 4b.

(a) (b)

Figure 4. Frozen sand columns; (a) Unreinforced and (b) Reinforced

The average bulk density of the sand prepared using this method was 1.9 Mg/m^3. Two column lengths were considered (a) 200 mm, representing a fully penetrating column and (b) 120 mm, representing a ‘floating’ or partially penetrating column.

When the column had been installed the composite clay/sand sample was removed from the consolidation chamber and a 200 mm high, 100 mm diameter specimen was prepared for testing in the triaxial cell.

In the triaxial cell the specimen was consolidated under 100 kPa of effective confining pressure. In each test full saturation of the specimen was ensured by applying a back pore water pressure. Due to the differences between 1-Dimensional loading and isotropic compression in the triaxial cell, this procedure produced a material with an undrained shear strength of approximately 27 kPa and an OCR of 1.4.

Following consolidation in the triaxial cell the specimens were loaded under undrained conditions in two different ways: (a) the entire surface area of the sample was loaded, similar to a standard CU test and (b) the centre of the sample was loaded, representing a foundation type loading (Fig. 5). The diameter of the foundation was 40 mm. Tests were carried out on specimens having either a reinforced or an unreinforced column of sand, 120 mm or 200 mm in length. In addition, a single test was conducted on a clay sample which did not have a sand column.

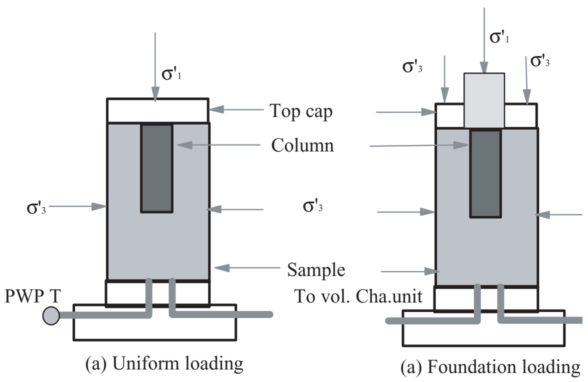


Figure 5. Loading types in triaxial cell

3 RESULTS AND DISCUSSION

Figure 6 shows the stress-strain characteristics of the composite clay/sand specimens subjected to uniform loading. The thick lines represent the characteristics of the specimens which had the geo-grid reinforced columns (Fig. 4b) while the thin lines represent the specimens which had the unreinforced columns (Fig. 4a). All samples were sheared under undrained conditions at a rate of 4% per day. In all cases, except in the specimens reinforced with 200 mm long columns, the pore water pressure increased as the samples reached critical state; this occurred at

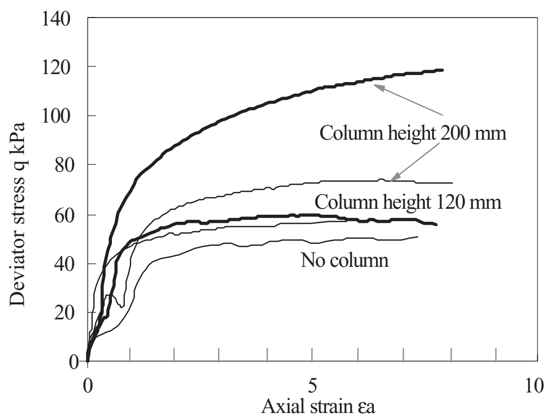


Figure 6. Stress-strain behaviour: uniform loading

an axial strain of about 4%. In the case of the 200 mm long geo-grid reinforced column the deviator stress continued to increase at a slow rate; this increase became insignificant at an axial strain of approximately 8%. A complex form of stress-strain behaviour was observed for the specimens having unreinforced columns. The results showed a reduction in strength followed by a recovery. This may have been due to the difference in the strength characteristics of the sand and the clay.

Figure 7 shows the undrained shear strength plotted against column length for both reinforced and unreinforced columns. The undrained shear strength of the clay without sand columns was approximately 27 kPa. The presence of the 120 mm unreinforced column increased the strength slightly. Any further increase in the strength after reinforcing the column with a geo-grid was marginal. In the case of the 200 mm column the increase in the shear strength is approximately 40% for the unreinforced column, rising to 125% when the column was reinforced. The amount of increase in undrained shear strength is significant between the reinforced and unreinforced columns; this improvement is entirely due to the confinement provided by the geo-grids.

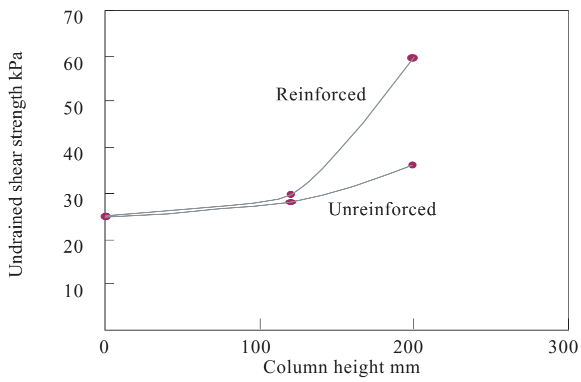


Figure 7. Relationship between undrained shear strength and column length.

Figure 8 shows the load:displacement characteristics for the foundation type loading. In this case, load was applied to the centre area of the sample only. It was applied under undrained conditions and the axial displacement rate was set at 4% per day. The load carrying capacity of the foundation increased by 60% in the case of the 120 mm column and it further increased when the column was extended to 200mm. The overall increase in the load bearing capacity is significant for the fully penetrating column reinforced with a geo-grid. This increase was in the order of 175%. However, as observed previously for the specimen subjected to uniform loading, the increase in strength was marginal when the 120 mm long column was reinforced.

Figure 9 shows the cross section of the clay/sand specimen after testing under the foundation type loading. The column length was initially 120 mm. The photograph clearly shows the lateral displacement or ‘bulging’ of the sand column beneath the foundation. The deformed shape of the column is in close agreement with the findings from previous laboratory studies (Hu (1995) and Hughes & Withers (1974)).

4 CONCLUSIONS

The performance of soft clay installed with columns of sand reinforced with geo-grids was examined under two different loading conditions: uniform loading and foundation loading. The results indicate that the overall performance of the soil can be increased by approximately 175% by installing columns reinforced with geo-grids. The practicality of installing reinforced columns needs careful consideration.

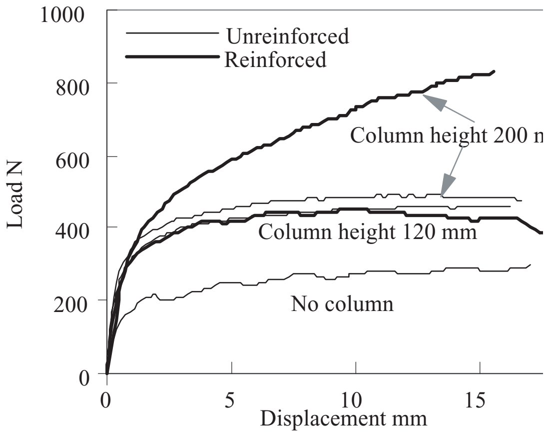


Figure 8. Load-displacement relationship for foundation type loading

Figure 9. Cross Section of the specimen after testing under foundation type loading.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

Bachus, R.C. & Barksdale, R.D. 1984. Vertical and lateral behaviour of model stone columns. In *In-situ Soil and Rock Reinforcement; Proc. Int. Conf., Paris 1984.*

Barksdale, R.D. & Bachus R.C. 1983. Design and construction of stone columns. *Final Report SCEGIT-83-104, Federal Highway Administration, Washington, D.C. 20590.*

Charles, J.A. & Watts, K.S. 1983. Compressibility of soft clay reinforced with granular columns. In *Soil Mechanics and Foundation Engineering; Proc. 8th European Conf., Helsinki,* 347-352.

Greenwood, D.A. and Kirsch, K. 1984. Specialist ground treatment by vibratory and dynamic methods. In *Advances in Piling and Ground Treatment for Foundations; Proc. Int. Conf., Instn. Civ. Eng., London,* 17-45.

Hu W. 1995. Physical modelling of group behaviour of stone column foundations. *Univ. of Glasgow. Ph.D. Thesis, June 1995*.

Hughes, J.M.O. and Withers, N.J. 1974. Reinforcing of soft cohesive soils with stone columns. In *Ground Engineering*, *Foundation Publications Limited,* 42-49.

McKelvey, D. & Sivakumar, V. 2000. A review of the performance of vibro stone column foundations. In *Ground Improvement Techniques; Proc. 3rd Int. Conf., Singapore, September 2000,* 245-254.