Experimental Study on Improvement of Soft Clay Using Sand Columns

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Abstract: Sand Compaction Piles (SCP) commonly known as Sand Columns (SC) now has been vastly used for reinforcing the range of soft soils. The installation of sand columns results in enhancing the ultimate bearing capacity of soft soil, increase the rate of consolidation, prevention of liquefaction in loose sandy soils and provide lateral resistance against the horizontal movement. This research aims at investigating the effects of floating columns in clayey soil with silty deposits by developing small scale laboratory models. The laboratory tests were conducted on a circular column of 37 mm diameter and results of the treated ground are compared to the untreated ground. The effects of sand columns on soils of different shear strengths (low-medium-high), slenderness ratio (L/D) of columns and different loading pattern are investigated. Group effect was also investigated by varying the spacing between the columns. The equivalent entire area of test model was loaded to determine the stiffness of composite ground and axial capacity of sand column was determined by loading the column area alone. Based on current study, it was concluded that sand column can significantly enhance the engineering properties of soft clayey soil. Also, the group effect was studied and it was concluded that by increasing the spacing between the columns, the group efficiency decreases. The axial capacity of sand columns decreases while increasing the spacing between the columns.

Key words: Ground improvement, sand columns, shear strength, slenderness ratio, group efficiency.

1. Introduction

Soft soils are generally not suitable for construction purposes because of their high compressibility and poor load carrying capacity. Such types of soils are usually required improvement prior to the any kind of construction activity. Various methods are introduced to improve the in situ soft soils. Among these methods, Sand Columns generally named as Sand Compaction Piles (SCP) method is the most effective and efficient method for ground improvement. Sand columns are now vastly used to enhance the engineering properties of soft soil for construction of highways and railway embankments. The major principle of this type of technique is to transfer the load of superstructure on the underlying soft soils without making substantial changes in the soil structure. It can be accomplished by installing column- or pile-type structures in a grid pattern into a bearing layer, on top of which often a load transfer mat consisting of geotextile or geogrid reinforcements is constructed, which results in reducing the settlement of the treated or composite ground, increasing the load carrying capacity of soft soil and hence increase shear strength. Mostly, the column type improvement techniques also act as vertical drain, which results in accelerate the rate of consolidation and thus reduces settlement after construction. These techniques can also be used for the foundation of tanks and warehouses. From the different techniques for modifying the actual ground conditions, granular columnar inclusions are supposed to be versatile and cost effective. Granular columns such as Sand columns or Sand compaction piles (SCPs) act as piles in soft soil and can bear load greater than the surrounding soft soil. Sand compaction pile (SCP) is a method of constructing large diameter sand columns in the ground. This technique of ground modification has been widely used for rapid improvement, and also in
near-shore regions for land reclamation works [1, 2]. Existing researches in sand columns show that the soil improvements through sand columns lead to high shear strength and low compressibility [3]. The sand column and the tributary area of surrounding soil of each sand column are simplified as a cylinder having the same total area although different available patterns and having an equivalent diameter or an effective diameter (De). This diameter was chosen so that the cross-sectional area of the unit cell is equal to that of the tributary area per column, i.e. (De=1.05 S) for the triangular pattern, (De=1.13 S) for a square pattern and (De=1.29 S) for the hexagonal pattern, where (S) is the spacing as defined in Fig. 1 [4, 5].

Aiban et al. [6] reported that soil density can significantly be improved by the installation of sand column treated soil ground as compare to the untreated ground. Loose deposits will be densified by inclusion of sand columns [6, 7]. Sand Columns provides a reinforcing effect, increases the horizontal effective stress and acts as a vertical drain. The implementation of sand columns have been recognized in different applications of geotechnical engineering such as the decrease in settlements of structures, reduction in earthquake induced liquefaction potential, increased bearing capacity of the foundation and improved stability of slopes. Sand columns have also been useful to increase drainage and enhance rate of consolidation and also reduce access pore water pressure in soft soils.

Aboshi et al. [8] reported that up to 50% increment in the undrained strength of soft soil is noted in about one month after the SCP installation at test sites in Japan. Numerous researchers have established equivalent properties of the treated ground using an elastic composite model for the sand columns and the surrounding soil. The surrounding soil undergo plastic deformation during the installation of the sand columns, as a result the expected performance of equivalent elastic models have not been achieved. The effect of sand column on soft soil is controlled by the combine effect void ratio and mean stress of sand and clay. Therefore, methods to quantify the performance of sand columns on weak soils must take their state into account. The critical state line provides a appropriate reference datum to study the combined effects [9].

In practice granular columns are normally constructed as end bearing piles [10]. The possible failure modes for a single pile are bulging, general shear and punching failures [11]. As reported by Hughes and Withers [12], end bearing and floating piles greater than three times their diameter in length generally failed by bulging near the top. Barksdale and Bachus [11] observed

Fig. 1  Typical arrangement of sand columns.
that the ultimate loading capacity of the single pile is increased as a result of an increase in the confining stress of the surrounding soft soil. Greenwood [13] reported that under an embankment, the lateral passive restraint around the columns away from the edge of the loaded area is much higher due to the equal all round influence of the applied load.

For a single granular pile, the most probable failure mechanism is often bulging failure [10]. The lateral confining stress around the granular pile is usually taken as the ultimate resistance, which the surrounding soil mobilizes as the pile bulges outward. Williams [14] conducted model tests, which showed that model columns failed by bulging near the top and that the load did not differ at failure irrespective of the length of the column. Similarly, small scale model tests were conducted by Hughes and Withers [12] and they reported that bulging developed over a depth of 2 to 3 diameters beneath the surface. Thus most of the approaches in predicting the ultimate bearing of a single, isolated granular pile have been developed based on the bulging failure mechanism. These include the cavity expansion approach and the passive pressure approach. Some of the different methods for estimating the ultimate bearing capacity are described below.

2. Experimental Setup

2.1 Test Program

A series of model tests of treated soil with sand column was performed in laboratory to study the efficiency of these columns in improving the load carrying capacity of soil. The steel moulds used for experimentation had the following dimensions; height = 360 mm, internal diameter = 300 mm, wall thickness = 6 mm and were locally assembled. Load tests were carried out in two steps; first on untreated soil and in the second stage on treated soil in a Compression Testing Machine.

2.2 Properties of Materials

2.2.1 Soil

Soil was collected from Jahangira District Sawabi, KPK, Pakistan. The soil was than pulverized in laboratory to conduct different tests to obtain various engineering properties like moisture content, grain size distribution, Atterberg’s limits, unconfined compressive strength and proctor compaction tests. The results are summarized in Table 1.

2.2.2 Sand

Locally available sand from Lawrencepur was used as backfill material in sand columns. The sand was thoroughly washed and oven dried, sieve analysis was performed and the angle of internal friction was found using direct shear test. The maximum and minimum dry density was found out to be 94 lb/ft³ and 89 lb/ft³. The physical properties of sand are summarized in Table 2. The gradation curve for virgin clay and column material is illustrated in Fig. 2.

| Table 1 Physical properties of soil. |
|--------------------------------------|
| Property                             | Results |
| Optimum Moisture Content (%)         | 24      |
| Liquid Limit (%)                     | 51      |
| Plastic Limit (%)                    | 28      |
| Plasticity Index                     | 23      |
| Shrinkage Limits (%)                 | 26.43   |
| Specific Gravity                     | 2.56    |
| Passing No. 200 Sieve (%)            | 100     |
| Silt Contents (%)                    | 40      |
| Clay Contents (%)                    | 60      |
| Maximum Dry Density (lb/ft³)         | 100     |
| Classification according to USCS     | CH      |
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![Particle Size Distribution of Clay and Sand](image)

**Fig. 2  Particlesize distribution of clay and sand.**

**Table 2  Engineering properties of column material.**

| Properties | G_s | Φ_s | γ_max | γ_min | Fineness modulus | Water absorption |
|------------|-----|-----|-------|-------|------------------|-----------------|
| Values     | 2.7 | 31° | 94 lb/ft³ | 89 lb/ft³ | 2.018 | 0.51% |

2.3 Preparation of Clay Bed

All the tests were performed on soft clay bed at three different shear strengths of 54 kPa, 32 kPa and 14 kPa. Before the preparation of clay bed, unconfined compression tests were performed in cylindrical sample of 40 mm diameter and 80 mm height. A relationship was developed between moisture content and unconfined compressive strength. Fig.3 illustrates the change in shear strength of clay with addition of moisture content. Moisture contents corresponding to desired shear strength were found to be 31%, 35% &39%. For preparation of each clay bed, oven dried clay sample was used and then required amount of water was added to soil to obtain desired shear strength and thoroughly mixed to form a uniform paste. A thin coat of oil was applied along the inner surface of steel container to reduce friction between clay and container wall.

The soil was filled in the container in six layers, each layer 50 mm thick after compaction. The soil was filled in the container up to a total height of 300 mm. The surface of each layer was provided with compaction energy of 12375 ft-lb/ft³ as in the case of Standard Proctor Test. Each layer was compacted with a tamper of 10 kg dropped from a height of 300 mm and given 70 blows. Care was taken to ensure that no significant air voids were left out in the test bed.

2.4 Construction of Sand Columns

After the preparation of soil bed, columns were constructed by a replacement method. A thin open-ended seamless steel pipe of 37 mm outer diameter and wall thickness 1 mm was pushed down into the clay at the centre of the steel container up to the desired depth. Slight grease was applied on the outer surface of the pipe for easy penetration and withdrawal without any significant disturbance to the surrounding soil. To avoid suction, a maximum height of 50 mm of soil was removed at a time. After removing the soil the column material were fed into the hole from top in
layers of 50 mm each. To achieve a uniform density, compaction was given with a 1.25 kg circular steel tamper with 15 blows of 100 mm drop to each layer. This light compaction effort was adopted to ensure that it did not create any disturbance in the surrounding soft clay by bulging laterally. The procedure was repeated until the column is completed to the required heights of L/D = 4, 5.5 and 7. After the installation of column, the top surface of the container was covered with plastic sheet for 4 days as curing period to ensure uniform moisture. After 4 days compression load test was carried out on each model.
2.5 Test Procedure

After preparation of model, the load-deformation behaviour was studied by applying vertical load on surface of untreated as well as treated soil in a compression chamber. A 100 mm thick steel plate with 200 mm diameter was placed at the centre of steel container to transfer the uniform load on soil. Strain gauges were attached to the upper plate to constantly monitor the settlement. The load was applied at a constant loading rate of 0.025 MN/min. Load was applied continuously until a settlement of 30 mm was achieved. The sample was extracted from the mould and soil surrounding the column was removed carefully to observe the failure pattern of the column. Fig. 5 shows the typical test arrangement for loading on equivalent entire area and column area. Equivalent entire area was loaded to determine the stiffness of composite ground while column area was loaded to estimate the axial capacity of sand columns.

3. Results and Discussions

3.1 Entire Area Loaded

In order to study the behaviour of sand columns, the load tests were conducted on untreated and treated soil samples by varying different parameters like shear strength of soil, length to diameter ratio of sand columns (L/D), and loading conditions (entire area loaded and column alone loaded).

Fig. 6 illustrates the load vs settlement curves of treated and untreated soil at L/D = 4.4 and shear strength of 54 kPa, 32 kPa and 14 kPa. The load bearing capacity for 30 mm settlement of sand columns treated soil samples increased significantly as compared to the untreated sample. It was observed that ultimate load carrying capacity of treated sample increased by 37% for same settlement, whereas, the ultimate loading capacity increased by 8% and 6% at 32 kPa and 14 kPa shear strength of soil respectively. This shows that sand columns are more effective in soft soils with relatively

![Fig. 5 Typical test arrangement: (a) equivalent entire area loading; (b) column area loading.](image)
higher shear strength whereas, less effective in week soils. Fig. 7 depicts the effect of shear strength on stiffness improvement factor.

Similar trend was observed by Ambily and Gandhi, [15], Asoka et al. [16] in their findings of model tests on granular columns. The behaviour of single column simulates the field behaviour of an interior column belonging to a group of columns.

Fig. 8 shows the effect of length to diameter ratio (L/D) of sand columns on clayey soil. It is observed that load carrying capacity is maximum at L/D=4, whereas, it decreases as L/D increases. A critical column length of 4 to 5 times of diameter of column (D) was identified by different researchers beyond which no significant increase in load carrying capacity was observed [17, 18].

3.1.1 Group Columns
Fig. 9 shows the effect of group sand columns on soft soil. The group columns are installed in triangular pattern with spacing to diameter ratio (s/d) of 2 and 3. In Figs.4 and 5, the comparison of untreated soil, soil treated with single column and soil treated with group columns is made. It is observed that settlement reduces as the s/d reduces at same loading which means that Load carrying capacity of sample with s/d = 2 is higher as compared to that of s/d = 3. Ambily and Gandhi [15] investigated the group effect of granular columns and reported that when spacing between the columns increases, the axial capacity of the column decreases and hence the settlement increases upto s/d = 3, after which no significant change is recorded.
Fig. 8  Effect of length to diameter ratio (L/D) at Su=32 kPa.

Fig. 9  Effect of group sand columns at Su = 32 kPa.

3.2 Column Alone Loaded

Sand Columns or stone columns may fails in bulging. Previous studies show that the granular columns may fails in bulging when subjected to axial loads. The bulging depth may vary from 2 to 3 times the diameter of column. Because of bulging, the lateral stresses on cohesive soil increases resulting in providing the additional confinement to the column. As a result, a balance condition occurs and vertical displacement decreases as compared to untreated soil [11, 19].

Fig. 10 shows the effect of shear strength on axial capacity of sand column. It can be seen that as shear strength decreases, the axial load carrying capacity of sand column decreases.

Fig. 11 shows the bulging of sand column. The bulging of sand column is observed at the upper portion of column and gradually increasing upto the depth of 1.5 to 2 times the diameter of sand column. The maximum bulging occurs at the upper portion of column where axial load is maximum and with depth, the bulging decreases due to less effect of stress on column. It is also noted that bulging effect become zero at full depth of column.

Fig. 12 shows the loading on column area and bulging behaviour of sand column after loading.
Fig. 10  Effect of shear strength on sand columns.

Fig. 11  Effect of L/D on behaviour of sand columns at Su=32 kPa.

Fig. 12  Loading on sand column and bulging of sand columns.
4. Conclusions

Based on current study, the following conclusions are made.

- The shear strength of clayey soils plays significant role in influencing the Sand columns or sand compaction piles. Behavior of sand columns in clayey soil with different shear strength (i.e. Su = 54 kPa, 32 kPa, & 14 kPa) is investigated in this study. It was observed that sand column is more effective in relatively higher shear strength as compared to week soil. Whereas, little increment in ultimate loading capacity of composite ground is noted in shear strength of 32 kPa and no significant improvement is observed at Su = 14kPa.

- The effect of length to diameter ratio is also investigated. The maximum strength increment is achieved at L/D = While increasing the L/D ratio, the loading capacity decreases. This is because of bulging of sand column in composite ground. Therefore, the critical length for partially penetrating column was observed to be 4 times the diameter of column.

- The influence of group columns is also determined; group efficiency is calculated by varying the spacing between the columns. As the spacing between the columns increases the ultimate load carrying capacity decreases. The group effect reduces as spacing increases.

- The single sand column tests with equivalent area loaded are well comparable with the group column tests. Single sand column will show the field behavior for an interior column when large numbers of columns are subjected to uniform loading.

- The bulging of sand columns is observed in top region of column where axial stress is maximum and bulging depth remain constant till the 1.5 times the diameter of sand column when column alone is loaded. However, in case of entire area loaded, there is no bulging occurs in sand column. The bearing capacity failure is observed while entire area is loaded.

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