Numerical Study of Behavior of a Group Pile Made of Pervious Concrete and Stone Aggregate

Jignesh Patel¹, Yogendra Tandel², Jerin Joseph³ and Chandresh Solanki⁴

Abstract—Stone columns are usually applied to improve bearing capacity of soft ground. They are also applied to tank foundations and nowadays stone columns are increasingly being used in small groups to support isolated footings in soft soils when conventional foundations are considered uneconomical. Stone column are used to increase the time rate of consolidation, reduce liquefaction potential, improve bearing capacity and reduce settlement. They provide primary functions of reinforcement and drainage, and in addition, improve the strength and deformation properties of soft soil in post installation and reconsolidation phase. The major limitation of the stone column is that they undergo excessive bulging, because of very low lateral confinement pressure provided by the surrounding soft clay soil. This limits their use in very soft clays and silts, and organic and peat soils. A new ground improvement method using pervious concrete piles provides higher stiffness and strength that are independent of surrounding soil confinement while offering permeability that is comparable to granular columns. This new method can improve the settlement performance of different structures supported on poor soils. A three dimensional finite element analysis of group of four composite piles consisting of different lengths of pervious concrete and stone aggregate under a square footing using the software package PLAXIS 3D was done. The influence of parameters like cohesive strength of soft clay, modulus of elasticity of pervious concrete and stone aggregate, spacing between piles and length of pervious concrete part of the composite pile on the load carrying capacity of the footing was studied. The results from this study shows that pervious concrete part of the composite pile helps in increasing load bearing capacity of the square footing.

Keywords—ground improvement, numerical analyses, pervious concrete pile, soft soil, stone column.

I. INTRODUCTION

INDIA has large coastline exceeding 6000 kms. Many of these areas are covered with thick soft marine clay deposit, with very low shear strength and high compressibility. The structures constructed on soft clays experience several problems like excessive settlements, large lateral flow of soft clay beneath the structures and loss of global and/or local stability. The popular remedial measure to overcome these problems is to improve the soil with the insertion of stone columns also called granular piles in regular grid. They provide primary functions of reinforcement and drainage [1], and in addition, improve the strength and deformation properties of soft soil in post installation and reconsolidation phase. When compared to traditional concrete or steel piles, conventional granular piers have low stiffness and strength that depends on the confinement provided by surrounding soil[2]. These disadvantages limit the use of granular piles in soft clays and silts, and organic and peat soils. Therefore, if an innovative type of pile can provide higher stiffness and strength with properties independent of surrounding soil, while still has high permeability, it will be more suitable to improve sites with poor soil conditions. Pervious concrete has the potential of satisfying these criteria.

II. PERVIOUS CONCRETE PILE

Pervious concrete piles are made of pervious concrete which is also called porous concrete, permeable concrete or no fines concrete. Pervious concrete is a special type of concrete with a high porosity used for concrete flatwork applications that allows water from precipitation and other sources to pass directly through, thereby reducing the runoff from a site and allowing groundwater recharge. Pervious concrete is made using large aggregates with little to no fine aggregates. The concrete paste then coats the aggregates and allows water to pass through the concrete. Pervious concrete is mainly used in pavement applications, including sidewalks, parking lots, tennis courts, pervious base layers under heavy-duty pavements, and low traffic-density areas.

Pervious concrete material [3,4] has a porosity ranging from 11–31%, a 28-day compressive strength between 5.5 and 26.0 MPa, and a permeability coefficient ranging from 0.25 to 0.54 cm/s. Pervious concrete can be made with a 28-day compressive strength ranged from 17.0–26.5 MPa and the permeability coefficient ranged from 0.02 to 1.03 cm/s.

When compared to the material properties of granular piles, the pervious concrete pile has higher strength and modulus with similar permeability. Furthermore, since the stiffness and strength of pervious concrete pile are independent of the confinement provided by surrounding soil, it can be used in very soft clay, silt, and organic and peat soils, in which granular piles cannot used. Ultimately, pervious concrete pile combines high strength of concrete piles and high

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permeability of granular piles which has the potential to result in more effective ground improvement technique.

![Fig. 1 Typical finite element mesh used in the analyses](image)

III. FINITE ELEMENT MODELLING OF GROUP OF PILES

The finite element analysis was carried out using PLAXIS 3D [5] which is a finite element package intended for three-dimensional analysis of deformation and stability in geotechnical engineering. The load deformational characteristics of the group were studied by modeling a group of 4 piles each having a diameter of 60 cm placed under a square footing and applying a displacement of 50 mm. The footing is square with length of 3m on each side. The three dimensional finite element model was made having dimensions of actual columns that are used in site. The columns (piles) were embedded in a soft clay layer of 5 meters and rests on a bottom layer of hard strata having a depth of 2 meters. Roller supports were used on the vertical face and fixed supports were used on the bottom of the second layer. The typical finite element mesh adopted is shown in Fig. 1. Mohr coulomb model was adapted for the stone column and the clay having linearly elastic perfectly plastic behavior. The pervious concrete was modeled as linear elastic. The zone between the columns and the surrounding clay is a zone with a very high difference in magnitude in young’s modulus of the order of ten times or more.

![Fig. 1](image)

IV. PARAMETRIC STUDY

A parametric study was carried out by varying various parameters like cohesion of the surrounding soft clay, Modulus of elasticity of the soil and stone column material, spacing between the columns and the length of the pervious concrete part of the composite pile. A base line case having dimensions as shown in Table I was chosen. The parameters were varied as shown in Table II. A total of 19 combinations were modeled using these parameters. The diameter of the columns was kept as constant of 0.6 m for all of the cases.

![Table I](image)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Soft clay</th>
<th>Pervious concrete</th>
<th>Stone column</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>Mohr-coulomb</td>
<td>Linear elastic</td>
<td>Mohr-coulomb</td>
</tr>
<tr>
<td>Behavior</td>
<td>Un-drained</td>
<td>Drained</td>
<td>Drained</td>
</tr>
<tr>
<td>Unsaturated unit weight (kN/m²)</td>
<td>15</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>Saturated unit weight (kN/m²)</td>
<td>17</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>Cohesion (kPa)</td>
<td>15</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>Angle of internal friction (deg)</td>
<td>0</td>
<td>-</td>
<td>40</td>
</tr>
<tr>
<td>Elastic modulus (kPa)</td>
<td>250 × Cₐ</td>
<td>15 × 10⁶</td>
<td>40000</td>
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<tr>
<td>Poisson ratio</td>
<td>0.49</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Dilatancy angle (deg)</td>
<td>0</td>
<td>-</td>
<td>10</td>
</tr>
<tr>
<td>Permeability (m/day)</td>
<td>0.00009</td>
<td>450</td>
<td>900</td>
</tr>
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</table>

![Table II](image)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cohesion of soft clay (kPa)</td>
<td>10, 15*, 20, 25</td>
</tr>
<tr>
<td>Elastic modulus of stone column material: Esc (kPa)</td>
<td>30000, 35000, 40000*, 45000, 50000</td>
</tr>
<tr>
<td>Length of pervious concrete column(pile): Lpc (times diameter of column(pile))</td>
<td>0#, 2, 4*, 6, 8, 34</td>
</tr>
<tr>
<td>Spacing of column(pile): s (m)</td>
<td>2d, 2.5d, 3d*, 3.5d, 4d</td>
</tr>
</tbody>
</table>

V. RESULTS AND DISCUSSION

The results of the numerical analysis comprise of load settlement behavior.

Effect of cohesive strength of soft clay

Figure 2 shows the load settlement behavior of soft clays reinforced with a composite piles consisting of 2.4m pervious concrete at top and 2.6m stone column at bottom. It is observed that the load carrying capacity of the pile group increases with increase in cohesion of the soft clay. The load carrying capacity of the soil having cohesion of 25 kPa is 2.12 times that of the one having cohesion 10 kPa. This increase is attributed to the increase in shear strength of clay with cohesion.

Effect of Modulus of elasticity of stone column material

The Fig. 3 shows the variation of load vs. settlement curves when the modulus of elasticity of the stone column material is changed. It is observed that load carrying capacity of the group of column increase with increase in modulus of elasticity of stone column material. It is noted that the load carrying capacity increases only 1.88% even if the modulus of elasticity of stone column has increased by 66.66%.
In this study the effect of various lengths of pervious concrete column has been modeled. This study included a full length stone column and pervious concrete column. The figure 4 shows the load vs. settlement curves when the length of the pervious concrete is increases. The Fig. 4 shows a clear increase in load carrying capacity of the group of columns with increase in length of the pervious column. The load carrying capacity of the full length pervious concrete column is 4.84 times the full length stone column group. There is a 52% increase in load bearing capacity when the length of pervious concrete column increases from 24% (2d) to 72% (6d) of the full length.

**Effect of spacing of the composite piles**

Figure 5 shows load vs. settlement behavior for change in spacing ‘s’ between composite piles. As the spacing increases, the load carrying capacity increases. Figure 5 shows the load vs. settlement with change in spacing, s. From Fig. 6 it is clearly seen that the load carrying capacity is highest in the case where the columns are at the edges of the footing. This may be contributed to the high stress concentration which occurs beneath the edges of a rigid footing. The load carrying capacity increases by 15 % compared when spacing is changed from s = 1.2 m to s = 2.4 m. Therefore, columns placed in this zone have the potential to absorb more loads and develop higher settlement improvement. The shear zones develops at the edges of footing as shown in Fig. 6 and extend to a depth beneath the center to the footing, positioning columns closer to the edge of the footings, and thus closer to these zones as shown in Fig. 7 results in enhanced settlement performance.
Fig. 6 Cross section showing shear zone developing at edges of footing (s = 2d)

Fig. 7 Cross section showing composite piles placed at edges of the footing inside the shear zone (s = 4d)

VI. CONCLUSION

The following conclusions are drawn from the present study.

(i) The load carrying capacity of the pervious concrete pile group was found to be very high compared to the stone column group.

(ii) The cohesive strength of soil influences the load carrying capacity of the composite pile group. As the cohesive strength of the soil increased from 10 to 25 kPa the load carrying capacity increased twice and showed less than 6% deformation in the stone column part of the composite pile.

(iii) The modulus of elasticity of stone column material does not play a significant role in the load carrying capacity of the footing they support. The load carrying capacity increases only up to 2% when the stiffness parameters of the stone aggregate increased by 1.6 times.

(iv) There was significant improvement in the load carrying capacity of the pile group when the length of pervious concrete in the composite pile increased. The load carrying capacity of the full length pervious concrete pile group was four and half times that of full length stone column group.

(v) There is a 50% increase in load carrying capacity as the length of the pervious concrete part increases from 2d to 6d. The base line case had more than 30% load carrying capacity than the full length stone column group.

(vi) The load carrying capacity of the composite piles was increased up to 15% when the spacing changed from 2d to 4d, which was near to the edge of the footing.

REFERENCES


