Analysis of the Efficiency of Piles built in Gravel Columns in an Experimental Model

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Abstract
Deep foundations are one solution in foundations of low load bearing capacity soils. There are different types of construction materials and these are selected depending on the structural loads and the type of works. Within time, the study on soils, especially on foundations, has greatly evolved and has served us to propose and verify the efficiency of new founding methods. One of these new methods is the use of piles built from gravel columns. In this research, an analysis of the efficiency of piles built with granular material was made in different soils: firm consistency clay, soft clay and medium compactness sand. The piles were subjected to different loads, always monitoring the strains throughout time. In order to carry out this research, an experimental model was made, and from the results we determined a higher efficiency in hard soils, even in soft soils and major strains in sand. With this experiment we could conclude that system as a recommendable founding method.

Keywords: Deep foundation, efficiency, monitoring, soil strains, granular material

1. Introduction
The function of foundations is to transfer loads from a structure to the resistant strata of the subsoil in a stable manner and with tolerable settlements during their lifetime. (SMMS, 2001). In order to define the most appropriate type of foundation that meets the aforementioned requirement, it is essential to accurately assess the loads to be transferred to the subsoil, as well as carrying out a detailed study of the soil mechanics and selecting the procedure that technically and economically is more viable (Sazhinet al, 1981). The selection of type of foundation depends especially on the mechanical characteristics of the soil, such as cohesion, internal friction angle, position of the phreatic level (water table) and the extent of the existing
loads (Padrón et al, 2011). From all this data, the permissible loading capacity is calculated and, along with
the homogeneity of the land, recommends us to use one or other type of foundation (Juarez y Rico, 1990).
Foundations can be classified according to different criteria, which will be useful if they allow to accurately
identifying the elements that will transfer the loads to the soil, as well as the failure mechanism of the
foundation soil for the application of the correct calculation method (Jimenez, 1990).

In some cases, when we start to excavate in order to start the works, we can come across with several
difficulties to locate the resistant soil stratum where we want to bed in, or we simply face the need to support
an isolated load on firm land, or on land that is hardly accessible by common methods (Motamed et al.,
2013).

Foundations can be extended horizontally in order to distribute the load, but they can also be vertically
developed down to the lowest strata able to support it. In these cases, deep foundation is the solution: it is
built with deep vertical concrete walls, slurry walls, or it could be built with driven columns or columns
bored in the land called piles. In order to identify the different elements of deep foundations, they are
classified according to their characteristics and work conditions, which facilitates the technical
communication between the consultants and the construction engineers, applying the proper criteria for each
activity. (Gordon, 1982).

Currently, there has been a wider array of problems in the different types of structures, which leads us to
analyze the current conditions of such structures, and also to realize that most of the time, these problems are
due to the characteristics of the area, the type of soil that causes problems on the foundation, and to the
structure itself.

Having different types of foundations allow us to reduce geotechnical problems; however, in certain cases
they are insufficient, and as a consequence we have searched more alternatives to overcome the present and
future problems. These alternatives will help us face a series of problems and will provide us with accurate,
reliable and efficient information.

In this research, we will discuss one of these alternatives: piles built with granular material. These piles
have the purpose of treating soft soils, improving them and increasing their load bearing capacity and
consequently increasing their stress resistance (Moss et al., 1998).

Currently, several foundations with different load bearing capacities are being used, and it has been
proven that there are different failures in the existing foundations due to factors such as bad construction
process, deficient quality of materials, area characteristics, etc., causing structural damage (Nagai, 1997).
These factors can cause failures that go from small cracking up to collapse of the structure. This is why
scientific and technological innovations developed in the Geotechnics field have generated improvements in
the existing methods; in our experiment, we refer to granular material piles, anchored on clay soils This
leads us to comparing this system with the conventional methods, observing its efficiency when subjected to
different loads. (Witlow, 2000).

The soft soil treatment with gravel columns consists of building a series of columns arranged evenly in
walls with different geometries: triangular, square, hexagonal, etc., in order to improve or reinforce soft soil.
This treatment has been developed as an extension of the classic vibroflotation technique, applied in
cohesive soils. Classic vibrocompaction or vibroflootation is an improvement technique useful in granular
soils, and it is a process in which the material is rearranged into a denser state by introducing a vibroprobe to
the land up to the desired depth. The vibroprobe penetration can be possible because of its weight, the amount
of vibration energy used in the process and an air or water flow, according to the type of vibroprobe.(Yao et
al, 2012). The main objective of this study is to analyze the performance and load bearing capacity of
granular material piles in soft soil, which strains can be monitored in an experimental scale model.
2. Materials and method

2.1 Experimental Model

In soil mechanics static problems, in order to have a similarity between the model and the prototype, the following equalities need to be met:

\[
\frac{Y_m L_m}{C_m} = \frac{Y_p L_p}{C_p} \quad (1)
\]

\[
\Phi_m = \Phi_p \quad (2)
\]

Where:

- \(Y_m\): density of the model soil
- \(Y_p\): density of the prototype soil
- \(L_m\): characteristic model length
- \(L_p\): characteristic prototype length
- \(C_m\): cohesion of the model soil
- \(C_p\): cohesion of the prototype soil
- \(\Phi_m\), \(\Phi_p\): internal friction angles of the model and prototype soils, respectively.

These equations mean the geometrically similar problems do not necessarily lead to similar results; unless the similarity rules expressed in such equations are met. According to equation 2, in granular soils we only need to geometrically scale the prototype for the resulting model provides us with similar results. In cohesive soils, we also need to scale, aside from the geometry of the problem, the density and the cohesion, in order to have a performance similarity in both the model and the prototype. Usually, to make a soil model, we take the geometry and characteristic length as a starting point; that is, we fix the length scale. Therefore, in order to keep the equality of equation 1, in very soft to soft cohesive soils, whose cohesion varies in between 0.1 and 0.5 kg/cm\(^2\), it is very difficult to do it only scaling its resistance because we would need to reduce the values of at least one minor order of magnitudes; equivalent to its resistance in liquid limit. It is also difficult to scale only the material density, because it will have to be increased by 10 (densities similar to those of lead or mercury).

2.2 Materials

To test granular material piles (gravel and sand), three different types of soil were used: hard clay soil, soft clay soil and medium compactness sand and the results of physical and mechanical characterization are shown on Table 1.

2.3 Methodology

For this experiment, a 1.20m x 0.80m x 0.75m caisson was built, considering the geometric scale proposed for the piles. Later, the cohesive material (clay) and the friction material (sand) were prepared, see Figure 1. Prior the preparation of material, we analyze the consistency grade for clay materials, and the compactness for sands, and compaction grades were established according to AASHTO compaction Standard. For hard clay, the soil was compacted with a tamper reaching a compacting grade of 98.36% of its Maximum Dry Density and optimum humidity (21.00%) measured in the AASHTO compaction Standard. For soft clay, an 85.20% of its Maximum Dry Density was compacted and optimum humidity in both materials in 5cm layers, of a total of 10 layers. For medium consistency sand, the process was similar.

Once the soil was prepared, we began with the mechanical test in this case cutting resistance extracting the cohesion and internal friction angle values (Table 1). Afterwards, the 3 cm diameter piles were perforated and we re-compacted the material with a tamper (Figure 2). Immediately after, the 8, 16, 24,
32, 40, 50, 62 and 72 kg loads were applied and were monitored for a 24 hours time or up to the first strain (Figure 3).

Results and Discussion
Of the three types of soil conditions, four pile tests were made, and their strains are discussed as follows:

3.1 Unit Strains
In this section, we recorded the model unit strains. For the hard clay we recorded values of 0.39 and 0.50 mm with an average value of 0.44 mm; for soft clay, we recorded values of 1.29 and 2.67 mm with an average value of 1.98; and finally, for medium compactness sand it was obtained values of 3.58 and 4.53 mm with an average value of 3.91 mm (Table 2). Maximum unit strains were observed on piles built on medium compactness sand, due to the readjustment and earth pressure of the granular materials that will occupy the empty spaces in the soil. A minor strain was recorded than in those built in hard clay. In Figure 4 we can observe the unit strains obtained and data corresponding to the type of soil, and adjusting the data to a lineal model, we obtained $R^2=0.89$.

3.2 Maximum Accumulated Strains
Maximum accumulated strains obtained were values of 2.28 and 2.65 mm with an average value of 2.48 mm for hard clay. Values of 6.34 and 8.69 mm and an average value of 7.32 were obtained from soft clay, and values of 9.07 and 11.72 mm and an average value of 10.30 mm were obtained for sand (Table 2). In order to record the strains of each type of soil we coo-related the maximum strains, and we could observe that a major strain was recorded on medium compactness sand, followed by soft clay, and that a minor strain was observed on hard clay. A lineal tendency was applied thus obtaining $R^2=0.84$, showing a high coo-relation taking bearing in mind the heterogeneity of tested soils (Figure 5). Figure 6 shows the path of deformation to applied loads, where a sudden deformation is observed at the beginning of the application of load and subsequently becomes constant to cero.

3. Conclusions
From the observations carried out and the results obtained in field from the loading tests we can conclude the granular/frictional soil show the largest strains. Piles built with granular material are adequate for soft and hard consistency soils, according to the performed loading tests. More testing should be made in order to verify the efficiency of the founding proposal here of described.

References


Whitlow, R. (2000). Fundamentos de mecánica de suelos, segunda edición, CECSA.


Table 1. Classification of the materials used in this experiment

<table>
<thead>
<tr>
<th>Test</th>
<th>Obtained Value, hard clay</th>
<th>Obtained value, soft clay</th>
<th>Obtained Value, soft clay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidity (W%)</td>
<td>30.99%</td>
<td>27.89%</td>
<td>12.91%</td>
</tr>
<tr>
<td>Simple grading</td>
<td>Gravel=0.00% Sands = 23.56% Fines = 76.44%</td>
<td>Gravel=0.00% Sand = 19.80% Fines = 80.20%</td>
<td>Gravel=0.00 Sand= 79.50% Fines = 20.50%</td>
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<tr>
<td>Water Limit (%)</td>
<td>42.00</td>
<td>38.70</td>
<td>17.30</td>
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<tr>
<td>Plastic Limit (%)</td>
<td>15.92</td>
<td>13.67</td>
<td>14.80</td>
</tr>
<tr>
<td>Plasticity Index (%)</td>
<td>26.08</td>
<td>25.03</td>
<td>2.50</td>
</tr>
<tr>
<td>Soil Classification</td>
<td>CL</td>
<td>CL</td>
<td>SM</td>
</tr>
<tr>
<td>SUCS</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Dry Density (PVSM)</td>
<td>1588.40Kg/m³</td>
<td>1541.90Kg/m³</td>
<td>1620.00Kg/m³</td>
</tr>
<tr>
<td>Optimum Humidity (W%)</td>
<td>21.00%</td>
<td>26.00%</td>
<td>8.10%</td>
</tr>
<tr>
<td>Compaction Grade (GC%), AASHTO Standard Test</td>
<td>98.36%</td>
<td>85.20%</td>
<td>95.91%</td>
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<tr>
<td>Solid Specific Weight (Ss)</td>
<td>3.01</td>
<td>2.95</td>
<td>2.55</td>
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<tr>
<td>Soil Density (γm)</td>
<td>1695.00Kg/m³</td>
<td>1615.00 Kg/m³</td>
<td>1550.00Kg/m³</td>
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<tr>
<td>Internal Friction Angle(φ)</td>
<td>22.5°</td>
<td>18.5°</td>
<td>35.0°</td>
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<tr>
<td>Cohesion (kg/cm²)</td>
<td>6.17</td>
<td>0.60</td>
<td>0.24</td>
</tr>
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</table>
Table 2. Maximum accumulated strains obtained for each material.

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>Performed test</th>
<th>Unit Strain (mm)</th>
<th>Maximum Strain (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard clay</td>
<td>1</td>
<td>0.44</td>
<td>2.57</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>0.42</td>
<td>2.28</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>0.50</td>
<td>2.42</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.39</td>
<td>2.65</td>
</tr>
<tr>
<td>Soft clay</td>
<td>1</td>
<td>1.29</td>
<td>6.34</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>2.67</td>
<td>8.69</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>2.03</td>
<td>7.34</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>1.67</td>
<td>6.90</td>
</tr>
<tr>
<td>Sand</td>
<td>1</td>
<td>3.58</td>
<td>9.07</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>4.53</td>
<td>11.72</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>4.05</td>
<td>10.54</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>3.82</td>
<td>9.85</td>
</tr>
</tbody>
</table>

Figure 1. Preparation of the cohesive material samples made of clay.

Figure 2. Performing perforations in the scale model.

Figure 3. Installation of the strainmeters and monitoring strains.
Figure 4. Unit strains in tested materials.

Figure 5. Maximum accumulated strains of tested materials.

Figure 6. Path of deformation to applied loads