A first version software programme for designing improved soils by vertical drains

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ABSTRACT: Designing embankments on highly compressible soils improved by vertical drains basically requires the verification related to the acceleration of primary consolidation. For this purpose a comprehensive methodology has been proposed which enables the determination of spacing between drains, in regular pattern, for a specified degree of consolidation to be attained in prefixed time. The suggested methodology has been programmed in first version of “GSVDrains” software.

1 INTRODUCTION

In practice there are two current approaches for designing vertical drains. The first one consists in using programmed methods use basic assumptions to estimate the using degree of consolidation. The second approach, reserved for projects that have little tolerance, involves the use of finite element or difference program to calculate the settlements. This second method is much more time consuming, and several soil parameters are required. In practice the first option is generally adopted. The aim of this paper is to provide a valuable tool for practical design of vertical drains, the emphasis being on the combination of an accurate prediction of primary consolidation settlement and the ease and speed of usage.

In this framework the elaboration of a software programme started since 2008 at National Engineering School of Tunis (ENIT), in collaboration with the Tunisian geotechnical consulting bureau SIMPRO. The first version of this software named “GSVDrains” is yet operating. The design scheme of vertical drains network can be undertaken by performing Barron (1947), Hansbo (1979) and Indraratna et al (2005) theories. For designing prefabricated vertical drains smear and well resistance effects are taken into account.

The first part of this paper is dedicated to basics about the use and performances of improved soil by vertical drains. In the second part, the methodology of design is detailed by focusing on approaches and methods for predicting the consolidation’s degree. Finally, two different case histories are treated in order to assess the predictions and opportunities given by "GSVDrains" software.
2 VERTICAL DRAINS (VD)

2.1 Description of the technique

The primary consolidation settlement of soft clay subsoil creates a lot of problems in foundation and infrastructure engineering. Because of the very low clay’s permeability, the primary consolidation takes a long time to complete. To shorten this consolidation time, vertical drains are installed in association with preloading by surcharge embankment or vacuum pressure. Vertical drains are artificially-created drainage paths which can be installed by one of several “methods” and which can have a variety of physical characteristics. Figure 1 illustrates a typical vertical drains installed under highway embankment. In this method, pore water squeezed out during the consolidation of the clay due to the hydraulic gradients created by the preloading, can flow a lot faster in the horizontal direction toward the drain and then flow freely along the drains vertically towards the permeable drainage layers. Thus, the installation of vertical drains in soft clay reduces the length of the drainage paths and, thereby, reducing the time to complete the consolidation process. Consequently, the higher horizontal permeability of the clay is also taken advantage. Therefore, the purpose of vertical drain installation is twofold. Firstly, to accelerate the consolidation process of the clay subsoil, and, secondly, to gain rapid strength increase to improve the stability of structures on weak clay foundation. Vertical drains can be classified into 2 general types, namely: sand drains, and prefabricated drains.

![Figure 1. Typical vertical drains installation under high embankment.](image)

2.2 Vertical drains characteristics

Early applications to accelerate consolidation of soft clay subsoils utilized sand drains. These are formed by infilling sand into a hole in the soft ground. Akagi (1979) asserted that the mere installation of the sand drains alone results in the consolidation of the soft clay because of large stresses induced during the installation. Thus, high excess pore pressure is generated and, after its subsequent dissipation, a gain in strength of soft ground is observed.

The diameter of sand drains varies from 20 to 25 cm (Magnan, 1983); while their length depends on the applied load and the degree of compressibility of soil layers. It should not exceed 15 m.

Adding to sand drains, the prefabricated vertical drains that can be defined as any prefabricated material or product consisting of synthetic filter jacket surrounding a plastic core having the following characteristics:
- Ability to permit porewater in the soil to seep into the drain;
- A tool by which the collected porewater can be transmitted along the length of vertical drain.
3 THEORETICAL CONSIDERATIONS

The design of vertical drains scheme aims at the determination of drains spacing which complies with the required degree of consolidation in a specified period of time for any given drain type and size in the ground conditions. In fact, Drainage will take place in both the vertical and horizontal planes and therefore any design methods should take this into account if it is to model the real situation properly.

The design of vertical sand drains system is generally based on the classical theoretical solution developed by Barron (1947) by which drains are assumed to be functioning as ideal wells, i.e., their permeability is considered infinitely high compared to that of soft soil to be improved. The assumption above is justified when the drain sand fulfills the requirements of an ideal filter, but in practice this can never be achieved.

The evaluation of vertical consolidation due only to vertical drainage only is based on the one-dimensional theory set out by Terzaghi (1943).

The assessment of the degree of consolidation due to horizontal drainage from soft soil to vertical drain is more difficult. From a practical viewpoint the drains must be installed in regular grid pattern and, therefore, axisymmetric condition does not apply. No analytical solutions exist for the 3D situation and it is usual to approximate the problem as for cylindrical drain placed at the centre of consolidometer.

Combining the vertical and horizontal consolidation, the total average degree of consolidation \( U' \) was presented by Carillo (1942) as:

\[
1 - U = (1 - U_h)(1 - U_v) \tag{1}
\]

\( U_h \) and \( U_v \) denotes, respectively the degree of consolidation horizontal and vertical.

Hansbo (1979) modified the equations developed by Barron (1947) for prefabricated vertical drain applications (PVD). The modifications dealt mainly with simplifying assumptions due to the physical dimensions, characteristics of the prefabricated drains, and effect of PVD installation.

Indraratana and Redana (1997) converted the vertical drain system into equivalent parallel drain well by adjusting the coefficient of permeability of the soil and by assuming plane strain cell.

4 PROGRAM DESIGN

Internationally, there are a limited number of softwares, enabling the design of vertical drains. Due to Internet limitations (procedures, model of design) in these softwares, the idea to develop a more generalized new tool of design reveals very interesting. In this way, it has been decided the elaboration of “GSVDrains” software. This tool considers the design of vertical drains by referring to approaches, above mentioned for studying the consolidation with vertical drains.

The design methodology adopted by “GSVDrains” is summarized in three principal steps. The first step considers the input of several data related to the choice of vertical drains type, the characteristics of initial soil (layers number and thickness, the horizontal or/and vertical coefficient of consolidation), and drains characteristics (diameter, length, discharge capacity and equivalent diameter of mandrel in case of PVD). The second step is devoted for the design assumptions and data, so it is necessary to specify the drainage path (otherwise end layer is permeable or not). For PVD, the ratio between horizontal permeability of soil and the permeability in the smear zone, and the diameter of the smear zone according to the mandrel diameter are required input. In third step, according to the sought goal and project data (figure 2), the design is carried out with several methods and conditions (taking account or not of smear effect and well resistance). As example, if the degree of consolidation \( U' \) and the corresponding time are input data (figure 2), the output results will be the spacing between vertical drains for triangular and square patterns (figure 3). In equivalent way the degree of consolidation and the spacing between drains can be used as input data, and then output results are the time and the degree of consolidation. Another option is also affordable, the spacing between drains and the time of consolidation are input data, and the software can predict the degree of consolidation of improved soil.
Once the type and geometry of foundation are specified, “GSVDrains” enables, for each pattern (triangular and square), the number of vertical drains and the required quantity of material i.e.: sand volume or lineal meters of PVD.

The evolution of the degree of consolidation or settlement versus time is drawn, when soil characteristics related to primary consolidation estimation are added in the software database.

5 STUDIED CASE HISTORIES

5.1 The exchanger of La Charguia (Tunisia)

The project consisted in bridge construction, crossing the road RN8 to access in the Industrial area of La Charguia. This bridge is designed by two juxtaposed aprons of reinforced concrete with four spans. Overall length of an apron is about 60.5 m (Hamdi and Hedhli, 2002).

After geotechnical campaign carried out under the embankments of access, the soil profile and recorded geotechnical parameters are described in table 1.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Origin</th>
<th>H (m)</th>
<th>Cc</th>
<th>e₀</th>
<th>cₛ (m²/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Fine sand</td>
<td>23</td>
<td>0.171</td>
<td>0.593</td>
<td>4.08 10⁻⁸</td>
</tr>
<tr>
<td>2</td>
<td>Clayey sand mud</td>
<td>5</td>
<td>0.193</td>
<td>0.581</td>
<td>1.61 10⁻⁸</td>
</tr>
<tr>
<td>3</td>
<td>Mud</td>
<td>22</td>
<td>0.342</td>
<td>0.844</td>
<td>2.30 10⁻⁸</td>
</tr>
<tr>
<td>4</td>
<td>Muddy clay</td>
<td>3</td>
<td>0.328</td>
<td>0.881</td>
<td>1.60 10⁻⁸</td>
</tr>
</tbody>
</table>

Characteristics of the embankments of access are summarized in table 2.
After one dimensional Terzaghi’s theory, the predicted settlement of unimproved soil under working load is about of 45 cm. Such unallowable magnitude of settlement needs to be accelerated before construction by vertical sand drains technique adopted by designers. The design consisted in regular triangular pattern of vertical sand drains of 30 m length and 30 cm diameter.

It is decided to reach a total degree of consolidation \( U > = 90\% \) in 6 months. Using, “GSVDrains”, after Barron and Hansbo theories, the spacing between drains is about of 2.1 m.

### 5.2 “Radès-La Goulette” bridge project (Tunisia)

The big project “Radès-La-Goulette” bridge which connects the north and south parts of the capital Tunis comprises four lots (Kanoun and Bouassida, 2008). Part of them is the construction of four embankments of access in north lake area. In order to accelerate consolidation settlement under embankments of final height varying from 5 to 6.5 m, prefabricated vertical drains (PVD) with preloading surcharge have been installed to a depth of 10 m depth. The proposed type of PVD is Mebradrain 88 (MD 88) which is of flat type of thickness 0.5 cm and 10 cm width. MD 88 was also used in previous soil improvement projects with PVD in Tunisia.

The characteristics of compressibility, measured from oedometric test for layer I down to 10-m depth), are presented in Table 3.

<table>
<thead>
<tr>
<th>Layer</th>
<th>Elevation (m)</th>
<th>Coefficient of consolidation (E-08 m²/s)</th>
<th>Unit weight (kN/m³)</th>
<th>( C_c/1 + e_0 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ia</td>
<td>-0.9 – 6.5</td>
<td>5</td>
<td>16.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Ib</td>
<td>-6.5 – 9.2</td>
<td>8</td>
<td>19</td>
<td>0.10</td>
</tr>
</tbody>
</table>

After Terzaghi’s theory in centre line of embankment, the primary consolidation settlement of sandy mud layer assumed as normally consolidated soil equals 1 m.

For this project, a squared pattern PVD spacing of 1.2 m and 1.8 m is adopted. Thus, the problem aims at determination of the necessary time to obtain a degree of consolidation equals to 90%. After “GSVDrains”, the time is deduced with several methods summarized in table 4.

<table>
<thead>
<tr>
<th>Methods</th>
<th>Spacing 1.2 m</th>
<th>Spacing 1.8 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barron (with smear zone)</td>
<td>46 days</td>
<td>120 days</td>
</tr>
<tr>
<td>Hansbo (with only smear zone)</td>
<td>68 days</td>
<td>169 days</td>
</tr>
</tbody>
</table>

From predictions in table 4, it is noticed the influence of spacing and the conservative time of consolidation predicted by Hansbo theory which considers a simplified spacing function compared to that suggested by Barron theory.
6 CONCLUSIONS

The aim of this paper was to set up a design tool to speed up the design of vertical drain installations in practice. As the program is elaborated with interactive interface, it is with benefit. Nevertheless the background of incorporated method remains relatively simple; it uses Barron (1948), Hansbo (1981) and Indraratana (1997) methods, which are well known and well used benchmarks for most of vertical drains projects.

The assessment of “GSVdrains” software by running field data from well documented case histories will enhance the degree of confidence of the elaborated first version. Once this step of validation, based on comparison between predicted results and field data projects, is done “GSVdrains” software can be commercialized.

REFERENCES

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