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Experimental analysis on the consolidation of Tunis soft soil improved by multiple Prefabricated Vertical Drains

Marwa Ben Khalifa[1], *Zeineb* Ben Salem[2], *Wissem* Frikha[3]

[1]Univ. de Tunis El Manar, Ecole Nationale d'Ingénieurs de Tunis, LR14ES03-Ingénierie Géo-technique, BP 37 Le Belvédère, 1002 Tunis, Tunisia
[2]Univ.de Carthage, Institut Supérieur des Technologies de l'Environnement de l'Urbanisme et de Bâtiment, 2 Rue de l'Artisanat Charguia 2 - 2035 Tunis, Tunisia.
[3]Univ. de Tunis El Manar, Ecole Nationale d'Ingénieurs de Tunis, LR14ES03-Ingénierie Géo-technique, BP 37 Le Belvédère, 1002 Tunis, Tunisia
Setec International 42-52 Quai de la Rapée Central Seine Building 75583 Paris Cedex 12. France

Abstract. The purpose of this paper is to experimentally investigate the consolidation of the reconstituted Tunis soft soil 'TSS' improved by Prefabricated Vertical Drains PVD. After geotechnical characterization, a consolidation test with vertical loading is performed on a mutli-drains cell, i.e. cell with soil improved by three drains installed in triangular pattern. The PVD used in this study is the Mebradrain 88 (Mb88) type which is commonly used in previous soil improvement projects in Tunisia. The test is conducted through a specific laboratory test apparatus "consolidometer". The settlements of soft soil specimen were measured during the consolidation test. Soil samples were extracted from different positions to measure water content ω variation after consolidation test. Results show that a significant water content reduction is observed after consolidation tests (approximately 64%) mainly at the vicinity of the PVD. Finally, the assessment of consolidation settlement was investigated using Asaoka's method. It's found that the ultimate settlement predicted by Asaoka method showed a good agreement with the measured value with difference less than 1%.

1 Introduction

Embankments on soft soils are one of the most common consolidation problems of soil mechanics. Primary consolidation of soft soil can take a long time, and in such cases, soil improvement may be required to shorten the consolidation time and increase the shear strength and thus the bearing capacity.

Prefabricated vertical drains (PVD) in combination with pre-loading have become a popular method of soil improvement in Tunisia for numerous infrastructure projects since the 1990s. This ground improvement method provides an effective and low cost solution to soft soil problems[1,2,3,4]. In fact, the Tunis Soft Soil (TSS) belongs to the category of

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problematic soils because of its weak strength characteristics, high compressibility and high content of organic matter (22%) [5].

Many approaches have been utilized for predicting consolidation settlement consolidation time which can conventionally be divided into three categories: empirical and theoretical methods, numerical modeling, and physical experiments.

The aim of the present paper is to experimentally study the consolidation of TSS improved by PVD. A specific laboratory test apparatus was designed and manufactured to run the consolidation tests with vertical loading which are performed on a mutli-drains cell. Three drains were installed in the soil specimen in triangular grid pattern. The experimental results of the evolution of settlement versus time of consolidation tests and the variation of the water content are discussed and interpreted. Finally, the assessment of consolidation settlement was investigated using Asaoka's method [6] and compared with experimental data.

2 Studied soil

The identification of the soil was carried out on reconstituted TSS sample obtained from Lac II in the North of Tunis City at a depth of 35m. The extracted sample has greyish green color with a characteristic smell and contains shells. A grain size analysis performed by hydrometer and sieve methods was carried out on extracted specimens (Figure1). Identification test results were summarized in Table 1. Following the Unified Soil Classification System, the tested soil is classified as Organic with high plasticity Clays.

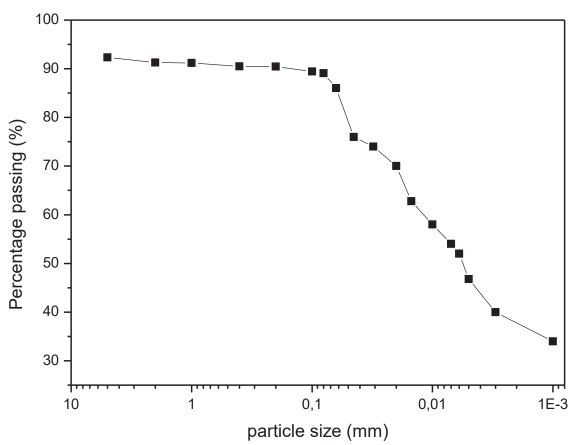

Fig.1. Gradation curve of Tunis soft soil

Table 1: Identification tests of TSS

Identification parameters		**Values**
Natural water content ω (%)		43
Grain size analysis	%<0,2mm	91,27
	%<80μm	89,1
	%<20μm	70
	%<2μm	35
Atterberg Limits	Limit liquid, L_l (%)	62.5
	Plastic Index, I_P	34.94
Unit weight γ (kN/m^3)		26.5
Calcium carbonate content Cca(%)		44.26
Organic matter content CMOC(%)		4.4992

3 Experimental procedure

In this experimental study, a specific laboratory test apparatus consisted of a consolidometer and a displacement gauge, was designed and manufactured to study the consolidation of the soil improved by PVD (Figure 2).

Fig.2. Consolidometer

Fig.3. Reconstitued soil

The extracted specimen was subjected to a reconstitution procedure by eliminating shell debris to obtain a homogeneous soil. This procedure consisted of wet sieving the natural soil through the 100-μm sieve. The sieved soft soil is air-dried until water content ω reached about1.2 times its liquid limit (L_l) [4,7]. Figure (3) shows the reconstituted soft soil specimen.
The reconstituted soil was placed in a cell consisted of a Plexiglas cylinder of 126 inner diameter and 290 mm height. Three geodrains are then placed in triangular pattern (Figures 4 and 5). The same spacing ratio of PVD ‘n’ was adopted ($n=D_e/d_w=18.8$) as Radès la

Goulette project. This ratio n is defined as the ratio between the equivalent diameter D_e and the diameter of geodrain d_w.The equivalent diameter D_e depends on the spacing between drains S and the grid pattern of geodrain. For triangular grid pattern, $D_e = 1.05xS$. The PVD used in this study is the Mebradrain 88 type which is experienced in previous soil improvement projects with PVD in Tunisia.
The reconstituted TSS is subjected to preloads increment of 21, 24.5, 28, 31.5, 35, 49, 52.5 and 56kPa, which is based on the preloading step-by-step undertaken in the case study of "Radès la Goulette" bridge project. Each preload increment was kept constant during 10 days at minimum to attain a stabilized settlement.

Fig.4. Insertion of three vertical drains

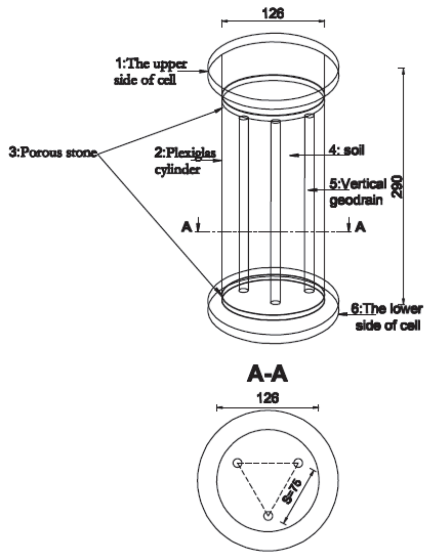

Fig.5. Multi-drains cell (all dimensions are in mm)

4 Results and discussion

Figure 6 presents the variation of settlement during time for preloads increments. It was found that the settlement for the multi-drains cell reaches 33mm at the end of the loading for a period of almost 2400 hours (100 days). After consolidation tests, soils samples were collected at different depths to measure the water content (ω) variation at two positions: at the vicinity of the drain (position D), and at the extremity of the cell (position E). The initial water content $\omega_{initial}$ is approximately equals to 75%. Figure 7 shows the variation in the water content with the soil depth. As it can be seen, a significant water content reduction is observed after consolidation test mainly at the vicinity of the PVD (approximately 64%) which corresponds to a dissipation of pore water during the primary consolidation of the soil sample. Furthermore, it is found that at the same depth, the minimum values of (ω) were recorded at the vicinity of the PVD which confirms the efficiency of the PVD in providing horizontal drainage. Besides, it is observed that the decreasing trend in water content is slightly greater at the bottom of the cell. In fact, compared to the initial water content ($\omega_{initial}$ = 75%), the average decrease in water content measured in the upper and the bottom of the cell were 61.4% and 67.2%, respectively.

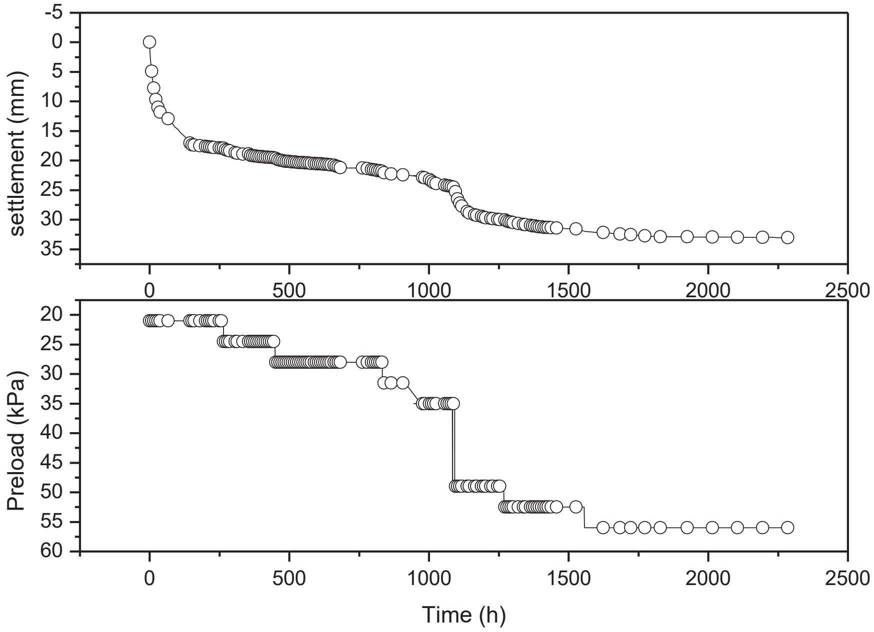

Fig. 6. Variation of consolidation settlement

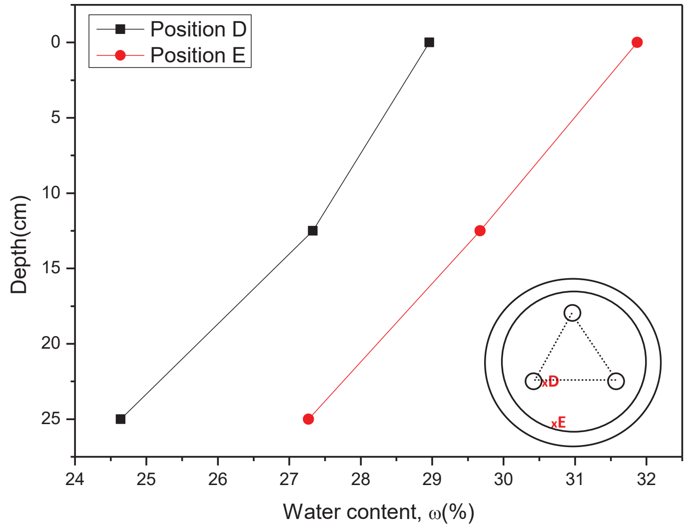

Fig. 7. Variation of the water content after consolidation test

Many methods for settlement prediction based on observation data have also been proposed. The Asaoka method and hyperbolic method are widely used due to their simplicity [6,8]. In the present study, the assessment of consolidation settlement was investigated using Asaoka (1978)'method [6]. This method is based on 'observational procedure' and derived from 1D consolidation equation. It is constructed by plotting N number of settlement measurements (sN) taken at equal time intervals (Δt) against the previous value (sN-1) for each reading. The expression for j[th]settlement value (sj) and time corresponding to that value t_j=Δt.j can be written as in Eq. 1 for each preloading increment:

$$s_j = \frac{\beta_0}{1-\beta_1} - \left(\frac{\beta_0}{1-\beta_1} - s_0\right)(\beta_1)^j \quad (1)$$

Where, β_0 and β_1 are the intercept and the slope of the straight line, s_0 is the settlement value at initial time.

Figure 8 presents an example of the correlation between settlement (sN) and (sN-1) from the observational results for the first preloading increment by taking the same time interval Δt=0.5h with initial settlement s_0=0.288mm. The best-fitted line to the data points on the Asaoka plot intersects the straight line as shown in Figure 8 with β_0 =0.299 and β_1=0.983.

Figure 9 shows the evolution of consolidation settlement predicted by Asaoka's theory and recorded from the multi-drains cell for all preloads increments. The experimental and the predicted settlements by Asaoka method slightly differ and are seemed to follow similar settlements rates. In fact, the ultimate settlement is equal to 33mm and 33.11mm, respectively. It can be concluded therefore that the predicted settlement obtained by Asaoka is slightly greater than that obtained by experimental measurement with difference less than 1%. Thus, the ultimate settlement predicted by Asaoka method showed a good agreement with the measured value.

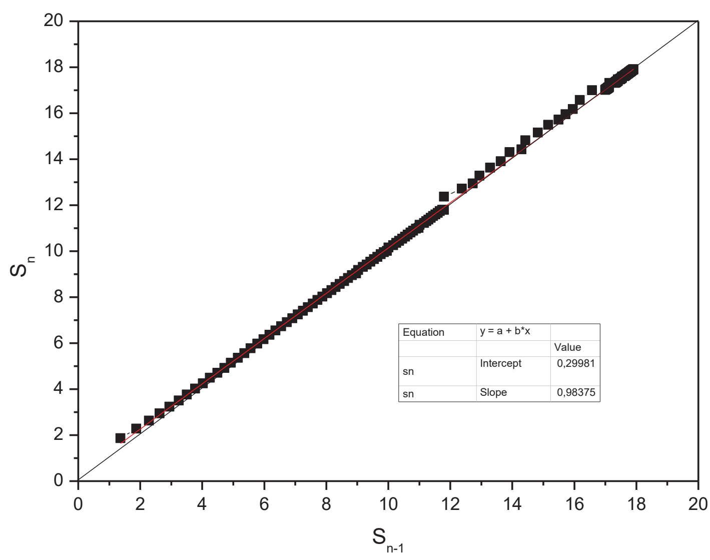

Fig.8. SN versus SN-1 plot for settlement of experimental measurements

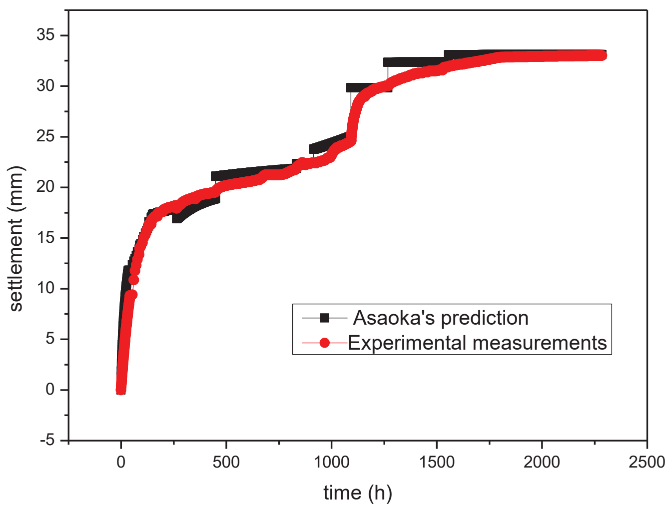

Fig. 9. Comparison between Asaoka's prediction method and experimental measurements

5 Conclusions

This paper presents an experimental investigation of TSS consolidation improved by multiple PVD. The results of this investigation indicated that a significant water content reduction was observed after consolidation tests (approximately 64%) mainly at the vicinity of the PVD. The assessment of consolidation settlement was analyzed using Asaoka's method. It was found that the ultimate settlement predicted by Asaoka method showed a good agreement with the measured value with difference less than 1%.

6 References

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