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Improve Geotechnical Design Parameter of Some Soft Clayey Soils

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Abstract

The shallow Soft Clayey deposit is common in Alexandria-Egypt. Most soft clays in their natural state are unsuitable for supporting any structure. Thus, improvement treatments exist to strengthen these soils so that improved soil can have adequate bearing capacity without undergoing failure or producing substantial excessive settlement post construction and applied loads to them. This paper presents a case study of an improved site in the city center, which reclaimed part of Maryout Lake, where the highly compressible clay with water content varies from 200% near the surface to 90% at the base of the shallow clay deposit. A prefabricated vertical drain with preloading has been used to improve this soft soil. Values of shear parameters and consolidation coefficient back-calculated from field measurements and have been compared with the values from lab and in situ tests. The study provides different relationships from comparisons of prediction and estimation compressibility and consolidation settlement from laboratory studies and particularly field case studies. Also, some correlation related to the compressibility with index properties of soft clay is presented. The results display that a substantial improvement is noticeable in the compressibility properties.

Keywords

Improvement, Soft Clay, Preloading, Vertical Drain, Bearing Capacity

1. Introduction

Generally, clayey soil exhibits noted changes in index properties with changes in its water content. Because the plastic soil usually have lower shear strength and is more susceptible failure bearing capacity when it is saturated. In Egypt, soft clays are widely distributed in the Central and Northern parts of the Nile Delta. The thickness of these soil layers ranges from one meter to more than 15 m. The soft clays in this region are generally brown to dark gray in color and are characterized by an abundance of organic matter of about 14% and high water content of 60% - 90%. They are also normally underlain by medium to coarse sand with gravel bed or sometimes peat soils, and overlain by medium to stiff clay soils [1]. Many researchers reported that limited or large depths of highly compressible normally consolidated clayey soil layers sustain large consolidation settlements as the result of the loads from large buildings, highway embankments, earth dams, etc. Pre-compression and provision of vertical drains in soft clayey soil may be used to minimize post-construction settlement, [2] [3] [4]. One of the recent methods for soft clayey soil improvement technique has used the vacuum pressure and surcharge preloading with combined prefabricated vertical drains (PVDs), [5] [6]. This technique has both low cost and effectiveness. In this technique, promoting rapid radial flow accelerates consolidation and decreases the excess pore pressure while increasing the effective stress [7]. In this paper, the results of soil investigations which had been carried out for the determination of engineering soil parameters for clayey soil at the site of the city center which reclaimed part of Maryout Lake—Alexandria-Egypt prior and after the improvement to asses' improvements are presented and discussed. The soil parameters were evaluated from laboratory tests and in-situ tests. Laboratory studies were conducted to evaluate the clayey soil index properties, water content, compressibility and shearing resistance Cao, L.F. [8], reported that one-dimensional consolidation tests are normally used for the determination of the compressibility and consolidation characteristics of soils of low permeability, (Win *et al.* 1998, Cao *et al.* 2001a). The field vane test, FVT standard Penetration test, SPT, and Cone Penetration test, CPT, were conducted in situ to assess shear resistance.

The observed field tests results presented that applied load and its duration are significantly compressibility properties and also increase the shear parameters of soft clay.

The aim of this work is to evaluate the changes in soft soil strength characteristics and how they are affected by applied different stress with increased soil permeability by using vertical drains, which are installed at different spacing before preloading the soft clayey soils area.

2. Study Area and Site Description

The area study is located in front of Alexandria International Garden. Plantations and weeds were covered the area. The site is to be reclaimed from Maryout Lake. Twenty-one borings forming a net cover the area studied was planned. A soil testing program was planned and performed on site and laboratory. The different soil profiles are shown in **Figure 1**. The subsoil formation at this area consists of fill composed of organic garbage mixed with sandy Silt, followed by very soft colloidal caly with some/trace crushed shells layer. The thickness of this layer was ranging about 6.0 m. to 9.0 m. This is followed by stiff to hard silty clay layer in thickness 7.0 meters. Finally appears a layer of very dense fine sand. An area along the shore of Maryout lake had been reclaimed, where the depth of the

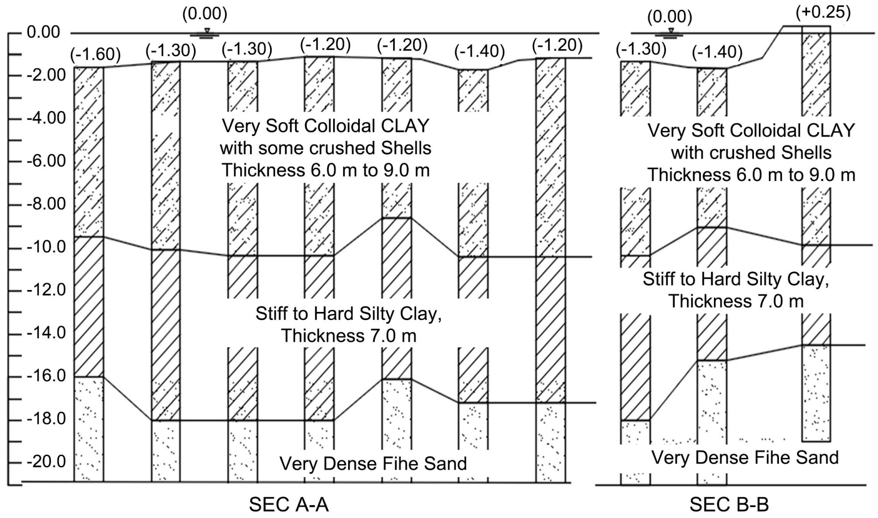

Figure 1. Sub-soil layers inthe studied area.

water in this area varies between 1.20 and 1.50 m. The bottom of the lake is composed of very soft compressible colloidal clay nearly at the liquid limit. The reclamation had been done by filling with a recommended graded granular material. This paper presented primarily the results of the earlier first phase of constructed city center Alexandriaarea investigation, the land reclamation process and soil improvement works that had been done.

Improvement Techniques

Because the excess pore pressure dissipates from the boundaries of the compressible soil layer, boundaries should be considerably more permeable than the clay layer itself as time goes, resulting in consolidation settlement. Drainers should be used to accelerate the consolidation settlement. This process is time-dependent and is a function of the permeability of the soil, the length of the drainage path and the compressibility of the soil.

Preloading with vertical drain (PVDs) had been used in improved the shallow clayey soil in this site. The vertical drains are used to shorten the drainage paths in order to accelerate the consolidation process and shorten the time required to squeeze the excess pore water pressure from the clayey soil. Also, preloading is that allows an immediate and direct assessment of its effects. The preloading process in this study involves dropping a heavy plate on the surface of the ground from a certain height as a parodic dynamic load-(typical a cycle duty crane is used to drop the heavy weight plate). Also, during the reclamation and subsequent improvement of the foundation clay by means of surcharge preloading was done. The extent of ground improvement asses in terms of shears strength and predict its future behavior.

3. Clay Soil Getechnaical Characteristics—Laboratory and Fieldtests Program

In the natural state of the soft clayey soils are loaded the excess pores pressures are generated and remain entrapped inside the soil pores because clayey soils have very low permeabilities. Consequently, the excess pore pressures generated by undrained loading dissipate slowly from the soil layer boundaries causing consolidation settlement. So, choosing the suitable improvement technique for any site subsoil, the suggested ground improvement should be justified with geotechnical investigation and design soil parameters to establish the reliability of the technical process. Groups of Laboratory and in situ tests were designed to study the effect of using top vertical drainage layer, (reclamation graded granular material layer), and central vertical drainage, (vertical drain (PVDs), in normally oedometer consolidation tests to determine the compressibility and consolidation characteristics of clayey soils of low permeability. Also, Atterberg Limits, water content and undrained shear resistance were obtained from standard lab tests. The field vane test, FVT, standard penetration test, SPT and cone penetration test, CPT was conducted in the situ to assess shear resistance prior and after improvements. In this paper some of the results will be reported and discussed. Theoretical and empirical equation will be used to evaluate the geotechnical design parameters and understanding of the geotechnical characteristics of clayey soil in study site.

3.1. Index Properties and Shear Resistance

Table 1 summaries the obtained results from laboratory and in situ tests of the very soft colloidal caly layerand followed sublayers prior and after the improvement. The obtained results for Atterberg Limits indicated that the soil of the studied area is classified as very high plasticity clay, (Fat Clay-CH). The soil moisture content, (wc), of the most studied samples indicated that it is near to liquid limit, L.L in the top layer. Figure 2 and Figure 3 show the obtained in-situ undrained shear strength for undisturbed and remolded clayey layer. The sensitivity of this clay layer indicates the amount of strength lost by soil as a result of thorough disturbance, [9]. Leroueil *et al.* [10] recommended the use of the undrained shear strength obtained from FVT, rather than that from the laboratory shear tests, because of sample disturbance in sensitive clays. Results of in situ tests show those vertical drains, which are installed before preloaded top soft clayey soils area accelerate the drainage of impervious these soils and thus speed up consolidation. These drains provide a shorter path for the water to flow through to get away from the soil and reduce time to drain clay layers from many years to a few months.

Table 1. Properties of soil layers.

Depth m.	Water content Wc %	Bulk density γkN/m^3	Plasticity index I_p	Undrained Shear Strength C_u kPa	Undrained strength at After Remolded C_{uR} kPa
2.00 - 5.00	75 - 200	12.2 - 13.4	60 - 100	30 - 45	15 - 25
5.00 - 9.00	88 - 100	13.4 - 14.4	60 - 100	45 - 75	25 - 50
9.00 - 14.00	38 - 68	15.1 - 16.5	75 - 90	90 - 110	50 - 60
14.0 - 25.0	-	1.70 - 1.75	-	-	-

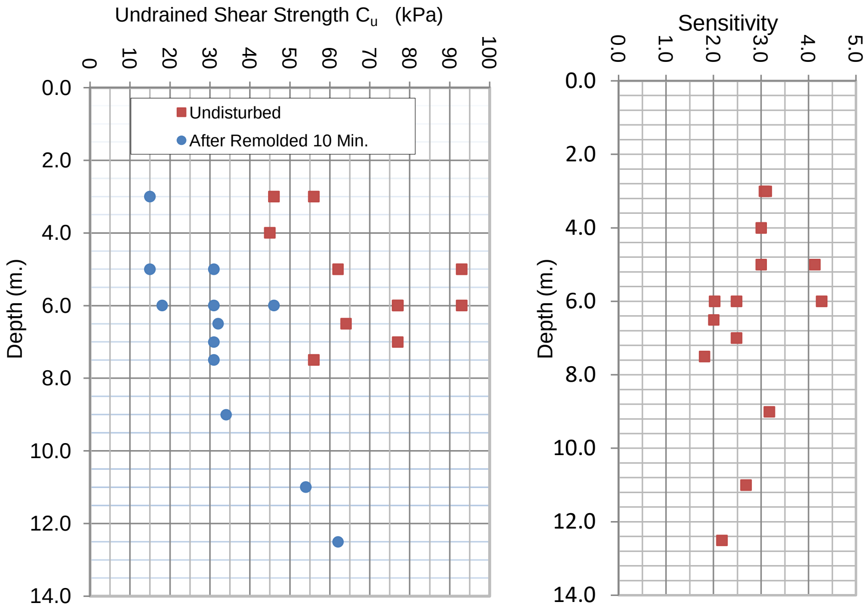

Figure 2. *In-situ* undrained shear strength and sensitivity for clayey soil.

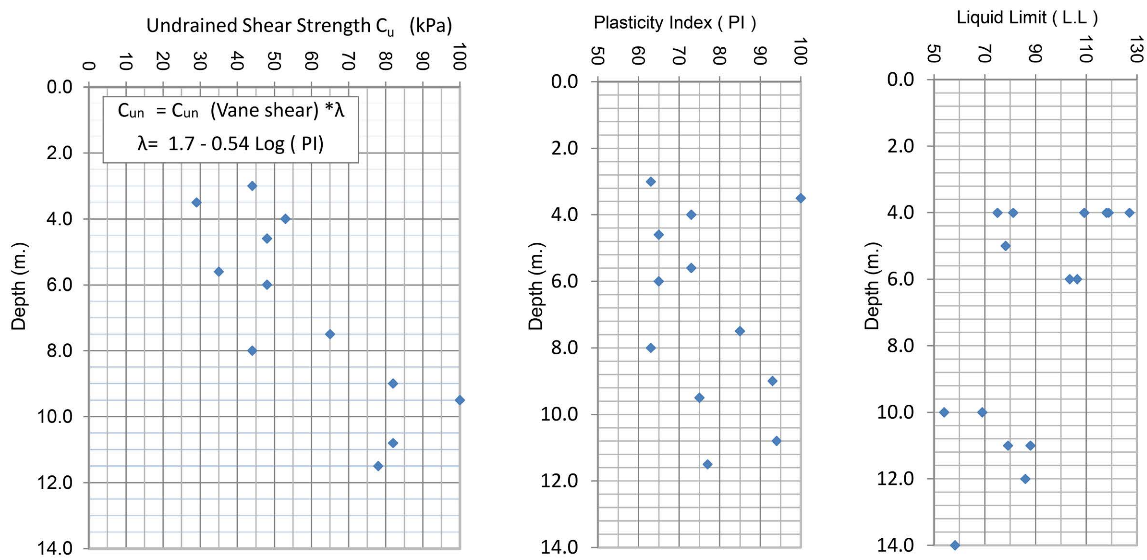

Figure 3. *In-Situ* Undrained shear strength, (after improved) and plasticity for clayey soil.

The above figures (**Figure 1** and **Figure 2**) indicate that the shallow layer is soft clay with mostly crushed shells layer, so the high measured magnitude of undrained shear strength Cu in the field is expected for the tested soil type; these high values of Cu is not real.

3.2. Compressibility Consolidation Tests

Many laboratory consolidation tests were conducted to study clayey soil behavior at the natural status and assess the reduction in its compressibility after improvement with vertical drain at different depths of clayey layers. Conventional standard one-dimensional consolidation tests with a soil specimen having a thickness 19.0 mm and diameter 63.0 mm were conducted in which the load on the specimen was doubled every 24 hours. The specimen is left under a given load for about 24/48/72 hours to study effect of load duration and determine the secondary consolidation which takes place before the next load increment is added. The clays continue settled sustained loading at the end of primary consolidation due to the continued readjustment of clay particles. Coefficient of secondary consolidation is defined as, $C\alpha = \frac{\Delta Ht/Ht}{\log t2 - \log t1}$.

Consolidation tests involving different drainage paths, top vertical drainage and redial vertical drainage in center of the cell were performed. The obtained test results are shown in Figures 4-10.

3.3. Discussion Test Results

Laboratory tests were conducted on natural and improved clayey soil with vertical drainage and vertical radial center drainage and some different relationships of the test results are plotted and analyzed. Also, it is interested in comparing evaluated values of the soil saturated hydraulic conductivity obtained from consolidation results shown in Figure 5 with the similar result obtained by applying of Kozeny-Carman equation for the determination of the hydraulic conductivity of compacted clayey soils, as reported as "The Kozeny-Carman equation provides good predictions of the of homogenized clayey soils compacted under given comp-active effort, despite the consensus set out in the literature", reference, [11]. The results from two procedures are approximately identified.

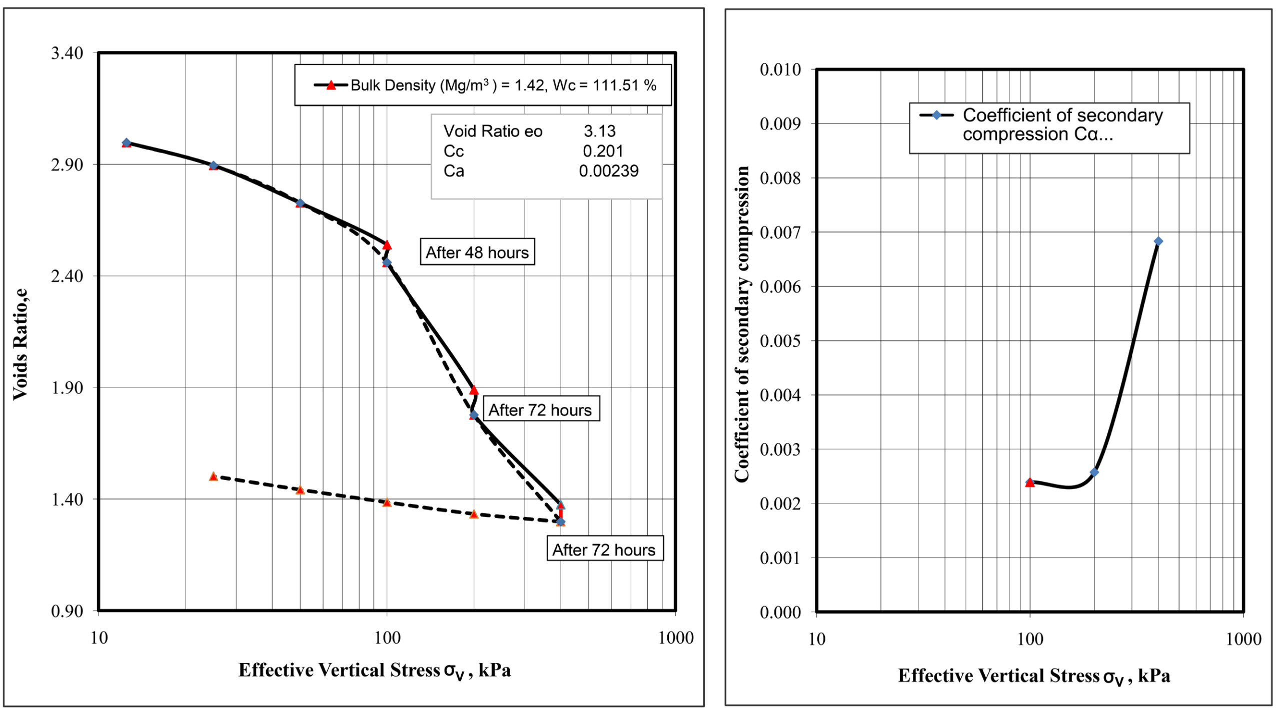

Figure 4. Secondary consolidation coefficient, Cα plotted against effective stress.

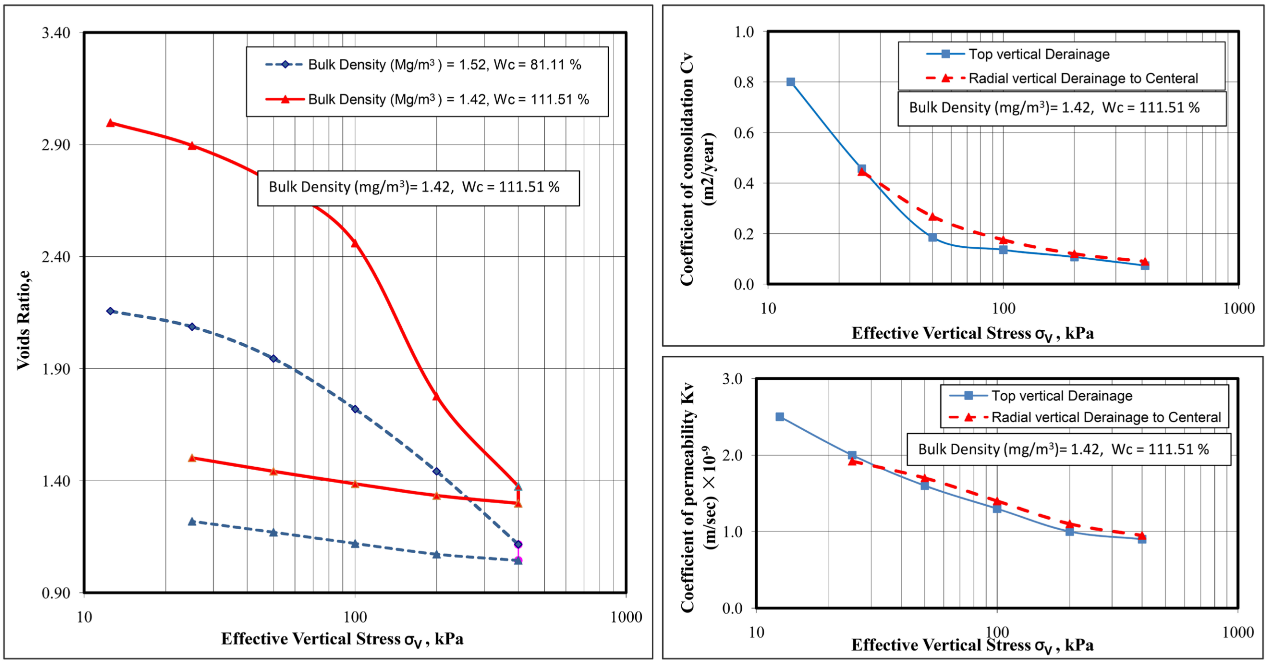

Figure 5. Consolidation Coefficient, C_v, Voids ratio, e_o and Permeability Coefficient k_v plotted against effective stress.

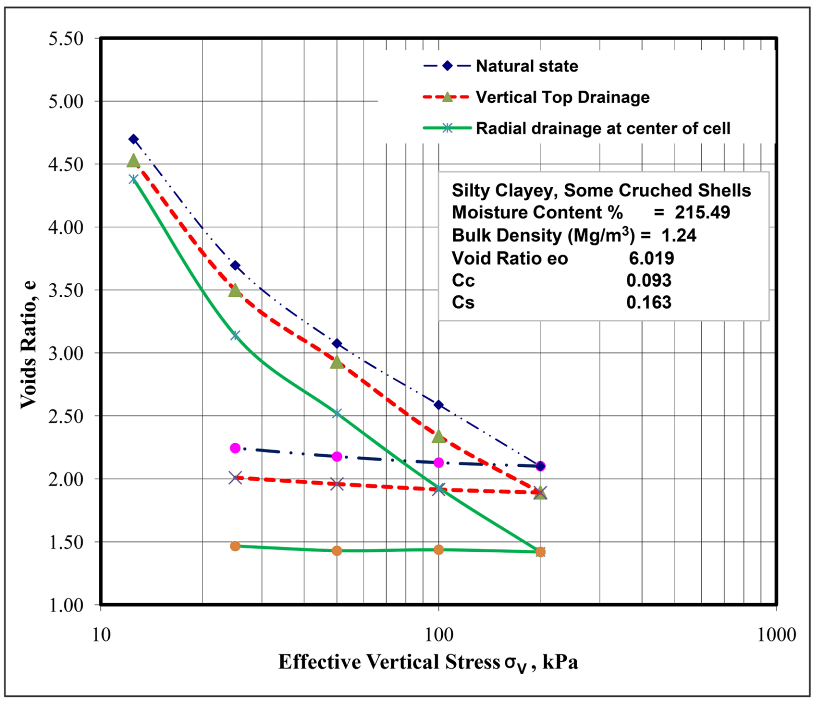

Figure 6. Effect of Vertical and radial Drainage at depth 3.00 m in Clayey Soil.

The top soft clayey layer is normally found under consolidation with ratios ranging between 0.45 and 1.0 (Figures 6-8). The pre-consolidation pressure $\sigma'o$ was estimated from the e-log ($\sigma'v$) curve using Casagrande's method. The test results can be pelted and represented in straight line relationships, as in Figure 9 and Figure 10. All the results obtained from laboratory and in situ tests, (direct shear test, consolidation test, FVT and SPT), indicate that the effect

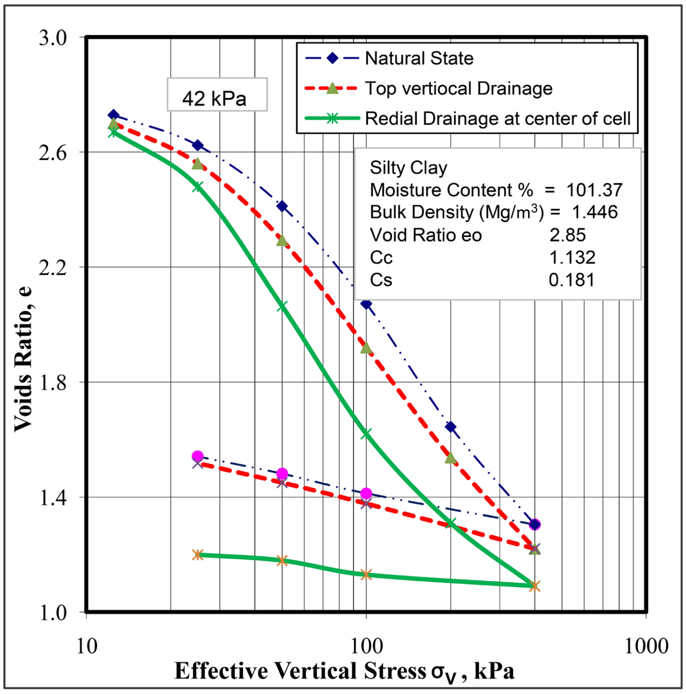

Figure 7. Effect of vertical and radial drainage at depth 5.60 m in clayey soil.

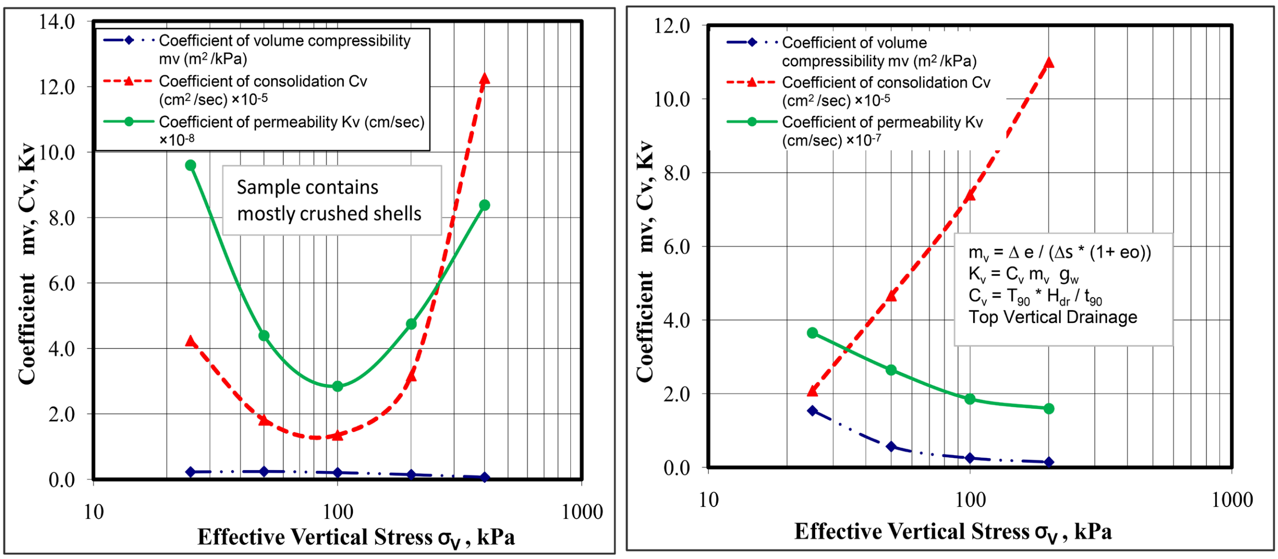

Figure 8. Effect of vertical drainage at depth 3.00 m and 5.60 m in clayey soil.

of improved soft clayey with top and redial vertical drained and preload accelerates consolidation settlement and increase the clay earlier strength. Field results indicated that the clayey soil containing mostly crushed shells has higher values of undrained shear strength Cu which is not true values.

From the test result, one can be compared, in detail, strength and settlement data obtained (in-situ tests and laboratory tests). So, this investigation work is helpful in developing a design curve of drain spacing, evaluated the preloading required according to achieve a required degree of consolidation in specified time period.

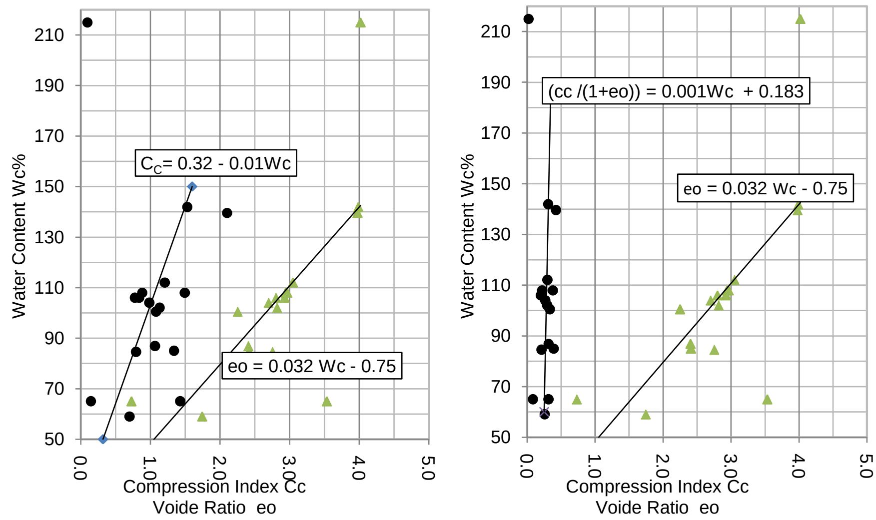

Figure 9. Effect of vertical drainage on compression index c_c and initial water content W_c%.

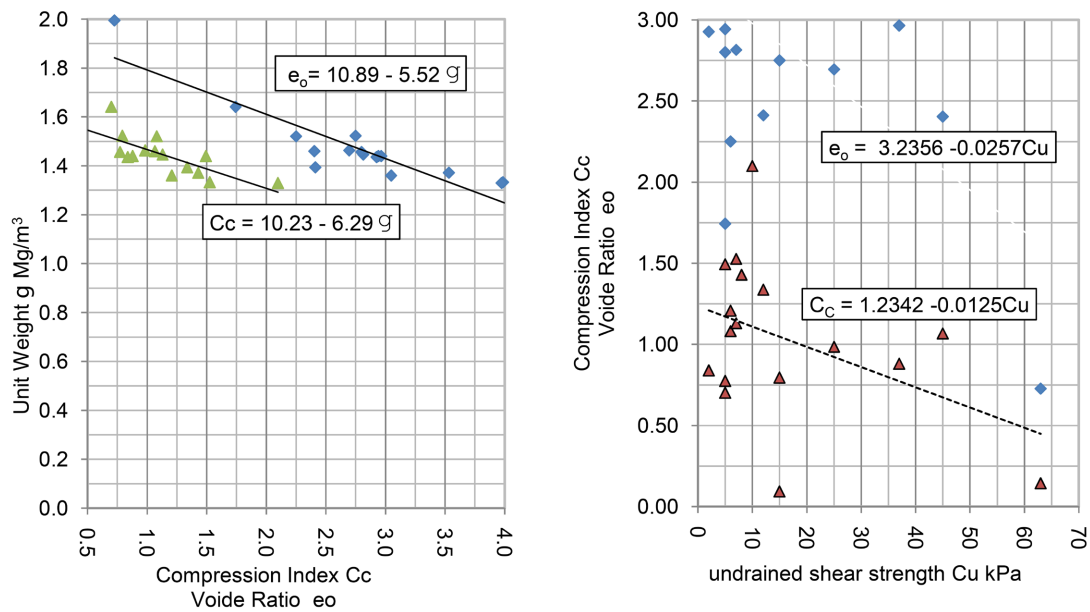

Figure 10. Relation between initial unit weightg, compression index c_c and initial void ratio e_o case of vertical drainage.

4. Conclutions

Some of the typical results of laboratory tests and in-situ tests prior to and after soft clayey soil improvement were presented and analyzed. It is founded that soil laboratory test is suitable for the study of the engineering properties of clayey soils and in-situ tests are useful tools to investigate the variation of soil properties and its performance after improvements.

In practice, in-situ tests are useful tools to investigate the variation of soft clayey soil properties with depth and the assessment of soil parameters. Undrained shear strength data at this site were acquired by in-situ vane testing, (FVT).

The results presented in this paper show that the very soft clays under applied stress have a high potential for settlement which can be improved their performance and properties using preloading with drainage technique. This technique was proven to be an economical alternative of deep foundation in our case.

All Obtained test results prove that vertical drains, which are installed before preloading the soft clayey soils area accelerate the water drained and speed up their consolidation, because the drains provide a shorter path for the water and reduce water time drains of soft clay layers.

Vertical drains and preloaded technique also increase strength parameters and increase the stability of soft clayey soils by reducing poe-water pressures.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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