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Soft clay soil improvement by preloading and wick drains, Exodo-Fertisa Project, Ecuador

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ABSTRACT

Consolidation settlements are a worldwide problem in different soil types, in which infrastructure works are built to develop a city or community. In the Ecuadorian coastal region, soft clay soils predominate, which generate excessive differential settlements, causing human losses and economic damage. This research aims to evaluate the consolidation of soft clays in Duran-Ecuador by applying preloading with wick drains and comparing it with geophysical tests (pre- and post-application) to analyse the consolidation rate efficiency. The methodology consisted of the following phases: (i) review of reference studies; (ii) analysis and interpretation of existing geotechnical data; (iii) technical evaluation of soil improvement with preloading and wick drains; and (iv) pre- and post-construction geophysical surveys (project serviceability). Soil consolidation analysis with no improvement was expected to require 81 months. At the same time, preloading and wick drains were achieved in 6 months, reducing the consolidation time by 90%. Moreover, settlements between 70-90 cm were excessively high according to the Ecuadorian Construction Standard, whereas settlements between 9-10 cm were expected by applying the improvement. Using geophysical tests, the improvement in the bearing capacity of the soil was determined through empirical correlations between the variation in electrical resistivity and soil void ratio. The combination of both methodologies (preloading and wick drains) in soft clay soils is an optimal solution for the reduction of consolidation time in the construction of a project.

1. INTRODUCTION

Consolidation settlement is a worldwide problem in soft clay soils, where infrastructure work is founded [1]. There is evidence of essential structures being affected by excessive differential settlement, such as the Pisa Tower in Italy and the Templo Mayor in Mexico [2].

Different soft-soil improvement methods involve different materials and installation techniques [3]. Jet grouting uses cement slurry or volcanic ash to improve the strength and stiffness of soil [4]. Semi-stiff inclusions are applied to columnar soils to reduce their overall and differential deformabilities [5]. Backfill preloading with vertical drains accelerates the consolidation process by decreasing pore pressure [6]. Removal and replacement techniques improve the soil-bearing capacity and resistance to shear stresses [7].

Preloading is one of the most commonly applied soil improvement techniques for consolidating soft clay strata [8]; however, time is a major constraint in this method. Therefore, they are widely used with vertical drains to accelerate the consolidation process [9,10]. The one-dimensional consolidation theory can be extended by including vertical drains that allow drainage in different directions, such as radial, vertical, and horizontal [11]. One of the vertical drains used are wick drains, prefabricated geotextiles that allow the reduction of the drainage distance of water in compressible clays using "tres bolillos" or triangular arrangements without being obstructed by fine soil particles [12], which allows a significant reduction in consolidation time.

Ecuador has diverse soil types owing to the heterogeneity of its geographical regions' climatic and meteorological conditions [13]. Duran is in the coastal region, which is characterised by the predominance of soft clay soils [14]. These generate excessive settlements with low load levels given that their consolidation time is longer owing to their low permeability [15].

What effects does the combination of preloading and wick drains in soft clay soil have on settlements in future civil works? The aim of this research is to evaluate the preload and wick drain combination in soft clays of the Exodo-Fertisa project (Duran-Ecuador) by conducting geophysical and geotechnical field studies to confirm soil improvement in civil works, the approach of guidelines, and the limitations of the method analysed.

2. STUDY AREA

The Exodo-Fertisa project, located at km. 8 Duran-Boliche road, represents a distribution and storage centre for agricultural products, such as fertilisers and herbicides, necessary for the development of crops, which enables a change in the productive matrix of farmers in the coastal region of Ecuador. This site includes our study area, the Fersal Aquaculture Livestock Warehouse, which has an area of 5,070 m^2. The infrastructure is located on soft clay soil with water table depths ranging between 2,00 and 3,30 m (before the rainy season), which, combined with the terrain's irregular topography, allows for flood valleys (Figure 1). This is evident in the study area, with a Rivera Quality Index (RQI) of 30 for the Guayas River, indicating intense alteration and poor water quality [16].

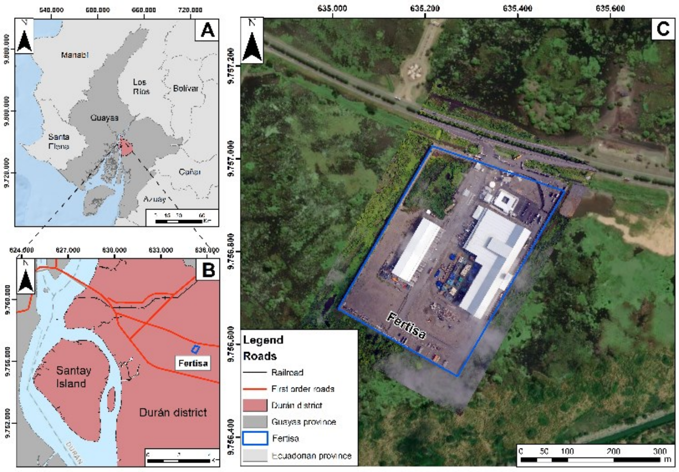


Figure 1. Geographical location of the study area (Duran-Guayas-Ecuador), with the delimitation of the Fertisa warehouse, where the preload with wick drains was placed.

The geotechnical conditions of the study area required settlement control within a specific period before construction of the project. As the duration of the consolidation process is a limiting factor, the densification of the ground through the preloading method (with compacted backfill) and wick drains, an effective method for short-term settlement control, was chosen [17].

3. MATERIALS AND METHODS

The methodology is based on the evaluation of the preload method and wick drains in a soft clay soil, applying geoelectrical (Geoelectric Tomography and Electromagnetic Survey), which correlates with geotechnical measurements, allows the assessment of the terrain enhancing, and therefore, the settlement mitigation and control. The following phases were defined: (i) review of reference studies; (ii) analysis and interpretation of existing geotechnical data; (iii) technical evaluation of soil improvement with preload and wick drains; and (iv) analytical study of pre- and post-geophysical data (Figure 2).

3.1 Phase 1: Review of reference studies

In the first step, a secondary review was conducted using search engines (Google Scholar) and databases (Scopus) on soil improvement methods for soft clays. This soil type is very frequent along the Ecuadorian coast, mainly in sedimentary basins [18]. There are several solutions to the same problem [19], but technical data were reviewed to properly select the improvement method to be used.

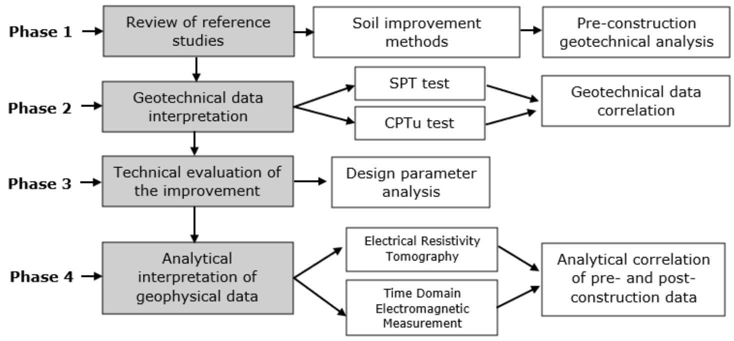


Figure 2. Diagram of the methodology used in this research, represented in two field phases and two research phases. SPT: Standard Penetration Test, CPTu: Cone Penetration Test with Pore Pressure Measurement.

Geological and geotechnical studies were carried out before the construction of the warehouse to detect soft soils prone to significant settlements, according to experience in the sector. Based on previous experience in similar terrains [20], it was decided to use complementary preloading and vertical drains to determine the speed and efficiency of the consolidation process.

3.2 Phase 2: Geological and geotechnical data analysis

For the analysis of the current soil conditions, a geotechnical investigation was executed at depths ranging from 20,50-40,71 m in November 2018 and May 2020. In addition, mechanical borings were performed with thin-walled Shelby-type tubes, taking "undisturbed" samples every meter for cohesive soils and a Standard Penetration Test (SPT) every meter for sandy soils or stiff clays. Cone penetration tests with pore pressure measurement (CPTu) allowed a more accurate estimation of the in-situ consolidation rate (Figure 3).

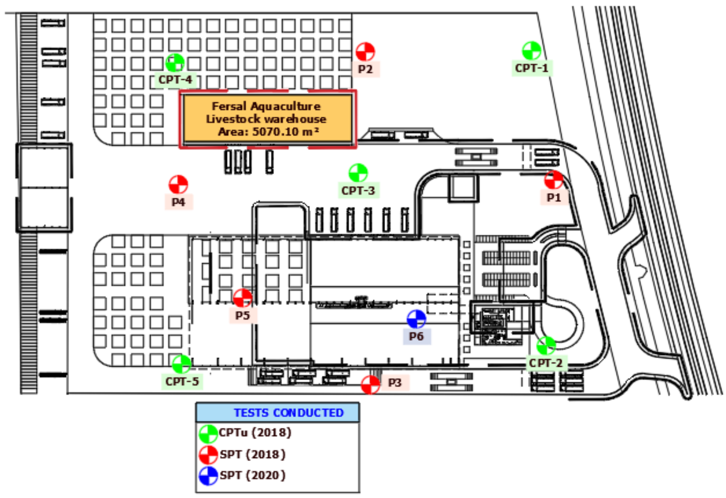


Figure 3. SPT and CPTu test locations performed pre-construction of the warehouse, within the study area.

Once the geomechanical properties of the subsoil were determined using three-dimensional analysis programs, the consolidation settlement in the soft clay soil was estimated. The consolidation process over time depends on the degree of dissipation of the excess pore pressure generated by the applied backfill load on the ground surface. Settlement calculations were performed for both primary and secondary consolidation. The immediate settlements that occurred mainly during the backfilling and construction of the foundation of the structure were also analysed.

Three geophysical tests were carried out (two Electrical Resistivity Tomography-ERT and a Time Domain Electromagnetic Measurement-TDEM), the locations of which are projected in Figure 4. ERT-01 is 100 m in length in the unimproved ground in the SE-NW direction, and ERT-02 is 80 m in length in the NE-SW direction in areas close to the Fersal aquaculture livestock warehouse in the Exodus-Fertisa project. TDEM-01 was carried out in an area without soil improvement, in a 40 × 40 m perimeter, reaching a depth of 106 m.

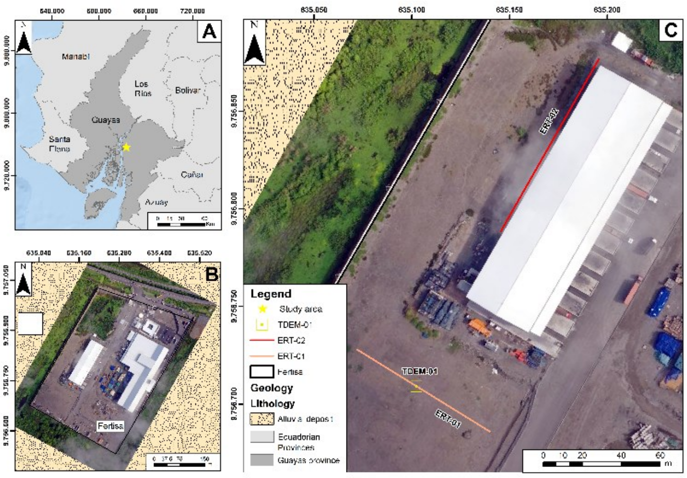


Figure 4. Location map of the geoelectric tests in the Exodus-Fertisa project, around the Fersal livestock and aquaculture warehouse.

3.3 Phase 3: Technical evaluation of the improvement method

The selection of the soil improvement method in the study area depended mainly on the consolidation time. Owing to the short time required to execute the Exodus-Fertisa project, preloaded fill material was planned to meet the required density and settlement conditions. However, in this case study, it was desired to accelerate the settlement process (to start the construction of the Fersal Warehouse); therefore, the placement and use of vertical drains were proposed to accelerate the consolidation process and improve the strength and stiffness of the clayey soils [21]. The implementation of the preloading, vertical drains, settlement plates, and piezometers is schematically presented in Figure 5.

The installation of prefabricated vertical drains (wick drains) was arranged in a triangular pattern (Figure 5), depending on the separation between the drains, depth, geotextile type, preload thickness, and soil permeability. Installing these vertical drains decreased the drainage distance within a compressible clay layer because drainage was facilitated horizontally and vertically, reducing the soil consolidation time. Another advantage of this method is that more economical shallow foundations will be used and not more expensive foundation methods, such as driven piles [22]. The depth that the vertical drains will reach varies according to the soil study because the soil reaches a sandy layer of medium to high density.

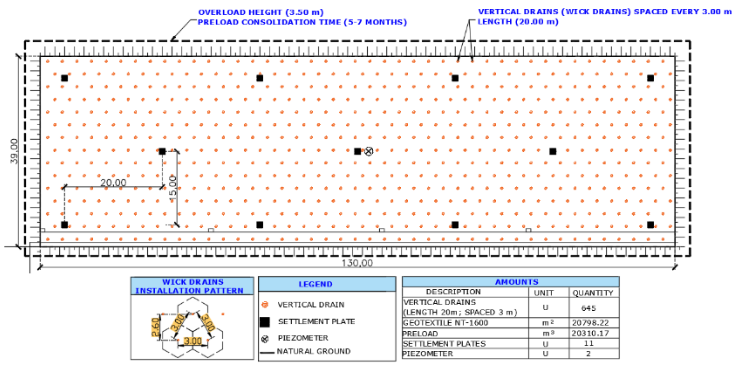


Figure 5. Improvement technique implementation scheme (location of wick drains with triangular arrangement), monitoring devices (settlement plates and piezometers), and quantity table: Fersal aquaculture livestock warehouse. Modified from [20].

The preload height was determined as the contact stress was significantly higher than the weight of the structure corresponding to the Fersal Warehouse. Therefore, it was decided to assume an even greater height so that the preloading backfill, once compacted, was at the level determined for the construction of the project. The scheme of overloads in the elevation under loose and compacted conditions is shown in Figure 6. With these techniques, the stress increase produces little settlement at the start of construction of the permanent structure. Reducing the spacing between vertical drains is not considered because this does not increase the permeability ratio [23].

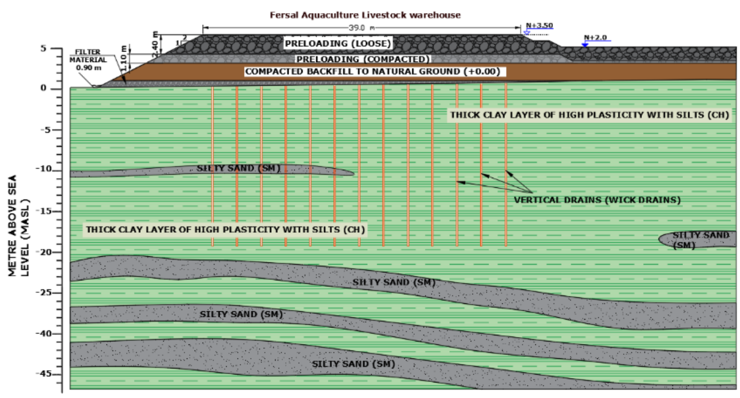


Figure 6. Schematic of preloading material used in the study area and materials obtained from SPT and CPTu tests. Modified from [20].

3.4 Phase 4: Analytical correlation of pre- and post-construction geophysical data

The ERT geophysical tests were carried out using the Terrameter SAS-1000 electrical resistivity equipment and a tomograph, whereas the TDEM tests were conducted using the ABEM WalkTem 2 equipment. The data acquisition methodology for ERT was equidistant electrode spacing by applying the Wenner configuration. ERT data were processed using licenced software Res2DINV, version 4.10.20. For TDEM, the data were processed using licenced software Aarhus Spia, version 3.6.0.1.

With the geophysical data (electrical resistivities), geomechanical parameters are correlated through equations presented by several authors, allowing the interpretation and comparison of the expected results.

4. RESULTS

According to statistical data, 22% of lower settlements have been reported for other improvement methods using wick drains with preloading [24]. Therefore, the selection of an appropriate methodology must be based on a planning strategy for analysing soil behaviour [25].

The water table depth plays a pivotal role in both the interpretation of the geophysical test results and comparison of the effectiveness of the upgrading method. It has been reported at a depth of -2,42m from the surface. During the rainy season, 38,6% of the area had a water table between 0,60-0,90 m, 11.68% between 0,30-0,60 m, and 18,2% between 0,00-0,30 m [26].

4.1 Geological and geotechnical characterisation

The study site predominantly comprises alluvial soils and marine clays formed by the estuarine deltaic complex and alluvial plain [27], belonging to the Holocene age as QTm Marine Terrace [28]. The Exodus-Fertisa project comprises intercalations of silty clays and sands, with the layer closest to the surface being an overconsolidated clay due to water table fluctuations in this 4,5 m thick layer.

Figure 6 shows the results of the field tests (SPT and CPTu), where the clay-silt and sand intercalations were verified. CPTu tests and soil borings are usually performed to characterise subsoil conditions [29]. Table 1 presents the results of the laboratory tests on the samples obtained in situ.

Table 1. Laboratory and in-situ test results (SPT and CPTu).

SPT	D (m)	Mat.	W (%)	FC (%)	LL (%)	PI (%)	N60
P2	20,5	CH	100	80	80	40	20
P4	20,5	CH	100	80	80	40	20
CPT	**H (m)**	**Mat.**	**BI**	**qc (MPa)**	**fs (MPa)**	**Mc (MPa)**	**Vs (m/s)**
CPT-3	21,8	CH	3	5	30	20	200
CPT-4	20,8	CH	3,3	5	30	20	200

Note: D: depth, Mat: material, CH: clay, W: moisture, FC: fines content, LL: liquid limit, PI: plasticity index, BI: behaviour index, qc: tip resistance, fs: shaft resistance, Mc: confined modulus, Vs: shear wave velocity.

The mechanical properties of the subsoil obtained from the test data in Table 1 were analysed, focusing mainly on the characterisation of its undrained shear strength and its level of consolidation to assess the speed and magnitude of its settlement. A lower overconsolidation ratio (OCR) indicates higher settlement and longer consolidation times.

4.2 Analysis of settlements, overloads, and applied improvement

Owing to the preload and weight of the structure to be built, the overloads to which the soil was subjected were analysed. Table 2 lists the stresses transmitted (Δσ) by the preload and overload at the level of the project elevation.

Table 2. Description of projected backfill heights and overloads.

Study area	Project level	Backfill height (m)	Δσ backfill (kPa)
Fersal Warehouse	+1,20	3,20	60
	Δσ overload (kPa)	**Δσ total (kPa)**	**Improvement implemented**
	60	120	Preload + wick drains

According to the soil parameters and using Settle 2D, its response was analysed without any improvement, resulting in primary deformations of 0,40-0,60 m and 0,10 m for secondary compression. Finally, total settlements were estimated to be between 0,70-0,90 m, with a consolidation time of 81 months [20].

To reduce post-construction settlement by consolidation in the study area, the method of preloading with compacted backfill and the use of 20 m long wick drains in a triangular 3 × 3 m arrangement was applied. The placement of a 3,20 m high compacted backfill made it possible to reach the project elevation for the Fersal Livestock Aquaculture Warehouse. This procedure allows the consolidation rate to be 5-8 months, obtaining settlements of 0,09-0,10 m, which represents a 90% reduction in waiting time (Table 3) [20].

Table 3. Estimation of wick drains + preloading by comparison of improvement alternatives for decision making.

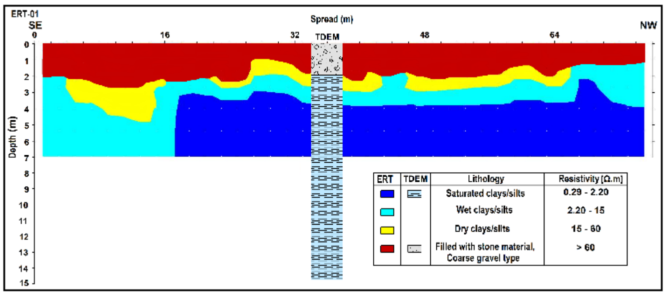
Improvement implemented	Consolidation time	Characteristics
Preload	81 months	Compacted backfill
Preload + wick drains	5-8 months	Triangular arrangement 3x3 m, length 20 m
Improvement implemented	**Expected settlements**	**Total stress**
Preload	0,70 a 0,90 m	100 kPa
Preload + wick drains	0,09 a 0,10 m	90 kPa

4.3 Pre- and post-construction comparison of soil parameters

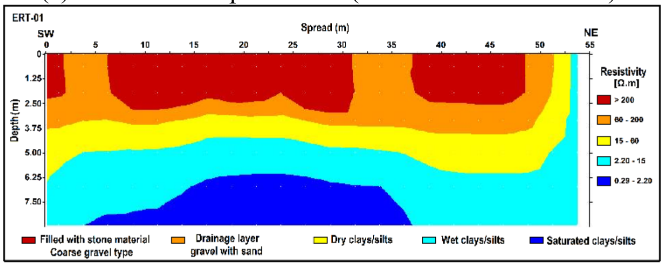
4.3.1 Correlation ERT-01 and TDEM-01 (Pre-Construction)

ERT-01, with a length of 80 m and inter-electronic spacing of 5 m, reached a depth of approximately 7 m and identified four layers of material (Figure 7a).

The first superficial layer with values greater than 60 Ω-m (red colour) represents a material with rock fragments corresponding to coarse gravel-type stone material filling with a variable depth along the profile of 1,60-2,00 m. Below this layer, the resistivity decreases to values between 15-60 Ω-m (yellow colour), with a layer of clay with dry to wet sand content and a thickness of approximately 1 m. To the northwest of the geoelectric profile, there are low resistivities of 15,0 to 2,2 Ω-m (light blue) corresponding to wet clays, whereas to the southeast (at a length of 16 m), at a depth greater than 4 m, the lowest resistivity values were recorded (<2,2 Ω-m, blue colour), indicating a saturated clay.



(a) Before soil improvement (ERT-01 and TDEM-01).



(b) After soil improvement with preloading and wick drains.

Figure 7. Soil stratigraphy through correlation of resistivity

In the central section of ERT-01, TDEM-01 (Figure 7) was performed, which verified the resistivity values obtained in the first 10 m. In the TDEM-01, three layers of material were identified, reaching a depth of 106 m. The first layer coincides with the ERT-01, with a 1,90 m thick gravel-type stone fill material, an underlying layer of wet to saturated clays/silt of 12,60 m and the third layer with a thickness of 91,90 m, corresponding to a layer of saturated clays/silt.

4.3.2 ERT-02 (post-construction)

ERT-02, with a length of 54 m and inter-electrode spacing of 5 m, reached a depth of 8,50 m (Figure 7b), differentiating five layers of materials.

The first layer, with an approximate thickness of 2,0 m (red colour), shows resistivities greater than 200 Ω-m, indicating a filling of coarse gravel-type stone material (gravel with silt and fine sand). The second orange-coloured layer has resistivities between 60-200 Ω-m, indicating the presence of gravel (drainage layer) with an approximate thickness of 1 m. In the third yellow layer, resistivities between 15-60 Ω-m were recorded, with a thickness of 1 m, indicating the presence of silty clay. In the fourth layer, light blue in colour and 2 m thick, resistivities range from 2,20-15,00 Ω-m, differentiating a clay with silt and high moisture content. Finally, a layer of very low resistivities (0,29-2,20 Ω-m) is observed, corresponding to saturated clays with silts.

4.3.3 Analytical interpretation of geophysical data

The systematic review related to soil behaviour highlights the following equations, which allow correlating geophysical parameters with geomechanical characteristics (Table 4).

Equation 1 was employed to calculate the OCR values based on the consolidation tests of the samples tested in the SPT test, thereby verifying the soil properties. By correlating the resistivities of the geophysical tests, the void ratio was obtained, a parameter that provides a more comprehensive understanding of the soil's consolidation process over time (Table 5).

Table 4. Equations relating geophysical parameters to geomechanical features.

No.	Equation	Description	Author
1	$OCR = k_{OCR}\left(\frac{qt-\sigma_{vo}}{\sigma'_{vo}}\right)^{1.25}$	OCR=Overconsolidation ratio	Robertson (2019) [30]
2	$A_v = 0{,}92 - 0{,}97e^{-\frac{\rho}{109}}$	Av=Compressibility ratio	Fallah-Safari et al. (2013) [31]
3	$w = 0{,}18 - 0{,}23e^{-\frac{\rho}{6.65}}$	w=Water percentage	Fallah-Safari et al. (2013) [31]
4	$S = \frac{\Delta e}{1+e}H = \frac{\Delta\sigma_v}{1+\sigma_{v0}}\xi H$	S=Total settlement	Apuani, et al. (2015) [32]
5	$C_c = \frac{\varepsilon(\Delta\sigma_v)}{\log\left(\frac{p}{p_0}\right)}$	Cc=Compression index	Bryson L. S. (2005) [33]
6	$\frac{\Delta\sigma}{1+\sigma v} = 3.233\frac{\Delta e}{1+e} + 0.023$	$\frac{\Delta\sigma}{1+\sigma v}$ Passed maximum pressure	Kibria et al. (2018) [34]

Table 5. OCR and e_0 values calculated from empirical equations

Soil type	Layer	Thickness (m)	Geotechnical evaluations		Empirical correlations	
			e_0	OCR	e_0	OCR
Clay with silt present	1era	4,0	2,0	1,5	2,6	1,4
	2nda	1,4	1,8	1,5	1,0	1,4
	3era	2,0	2,5	5,0	1,4	5,0
	4ta	4,0	1,0	5,0	2,0	5,0

Subsequently, settlements were calculated based on the change in the void ratio, using equations 2, 3 [31], and 6 [34]; likewise, soil deformations were evaluated using the factor ξ, which relates the conductivity and void ratio through equations 4 [32] and 5 [33] (Table 6).

Table 6. Values and comparison of total settlements, calculated from empirical equations.

Empirical correlations		Geotechnical evaluations	Difference (%)
Equation	Settlement (m)	Settlement (m)	
Fallah-Safari et al. (2013) [31]	0,79	0.90	12,20
Apuani, et al. (2015) [32]	0,45		50,00
Bryson L. S. (2005) [33]	0,81		10,00
Kibria et al. (2018) [34]	0,52		42,20

5. RESULTS DISCUSSION

The settlements calculated from geotechnical parameters (Settle 2D) were considerably high, between 0,70-0,90 m, consolidating in 81 months without any improvement [20]. As a storage warehouse, the project had to be constructed within the shortest possible time; therefore, accelerated consolidation was required. The improvement technique was the use of vertical drains (wick drains) and a preload, which, by removing the water and air in the clay layers, reduced the consolidation time (5-6 months), resulting in settlements of 0,09-0,10 m, reducing deformations by approximately 90%. In the Port of Cadiz, wick drains, and a preload of 5,5-12,0 m were used for six months, where settlement measurements of 0,57 m were obtained in slabs, which after removal of the overload were reduced to 0.52 m (9% of the original settlement) [35]. In the Main Building of the Canadian Port of Entry in Windsor, a preloading procedure with wick drains was performed, where settlements of up to 1,05 m were observed with a consolidation time of 12 months before the removal of the overburden, and a gain of between 40% and 100% of undrained shear strength was achieved [24]. On the other hand, in a shopping centre in Florida on fills of anthropogenic origin and residual soils, a settlement of between 0,15-0,25 m was expected, a wick drains fill, and a rock fill was chosen, whose consolidation process was completed in 3 months, reducing settlements to 0,03-0,19 m [17].

Geophysical tests allow quick and cost-effective exploration of the soil, and the stratigraphy of the soil can be determined to a certain extent using resistivity values [36,37]. Geophysical techniques that measure electrical resistivity are susceptible to water or voids [32,38]; therefore, electrical conductivity decreases with increasing pressure, improving consolidation owing to the dissipation of pore water. In a study in the Mexico Valley basin, where a 2,8 m preload and prefabricated vertical drains (wick drains) were used, piezometers were used to measure the dissipation of excess pore water pressure in this 53-month test [39]; almost total dissipation was verified at the end of the period.

The pre- and post-construction geophysical tests showed a representative increase in soil resistivity, differentiating four main layers of varying thicknesses. The predominance of soft saturated clays with very low resistivities, between 0,29 and 60,00 Ω-m, was observed in the natural soil before the construction of the project. Likewise, the soil characteristics were modified by executing the soil improvement with wick drains, resulting in higher resistivities between 0,29 and 200,00 Ω-m, implying greater soil stiffness due to the vertical drains and preloading. In comparison to a case study in Jiangsu, China, patented Electrically Conductive Wick Drains (ECWD) have been presented which, with a resistivity of less than 10^{-3} Ω-m, manage to lower the moisture content from 62% to 39% in soft clays in 36 days [40].

The depth of the water table depends on the season in which the in-situ tests are analysed, considering that the study area is prone to temporary flooding during the rainy season [41,42]. Therefore, hydrological analysis should be conducted to determine the historical water table elevation and establish the lengths and elevations to design the vertical drain arrangement. In a project carried out in Colombia, a comparison was made between a scale model of vertical drains and their finite element software model to establish stresses and deformations, which requires an adequate estimation of the water table, proving that the consolidation time is 84% less using wick drains [43].

From the analytical evaluation of the geotechnical and geophysical tests using empirical correlations, it was found that the OCR and void ratio data calculated from the SPT, and CPTu tests are related to the data obtained from the geophysical tests (ERT and TDEM) [44]. The void ratio is the primary factor determining the settlement, which is dependent on the electrical resistivity [45]. In contrast, inverse resistivity shows a bijective correlation with water content [46], a secondary factor [47]. A project in Indonesia on the Trans-Java highway showed that prefabricated vertical drains accelerate the consolidation rate by up to 90% within one year, as proven by geoelectrical resistivity investigations similar to this study [48].

The settlements calculated by geotechnical testing are close to those obtained empirically using formulas correlating geophysical (resistivity) and geotechnical (void ratio) parameters, as demonstrated by the values determined for the upgrading carried out in the Exodus-Fertisa project. However, in a project in Alexandria (Egypt), where 6,5 m preload and wick drains were used, a settlement of 0,74 m was reached. However, the recovery after removal of the preload was 0,72 m (i.e. a recovery of 3% of the original settlement) [49].

Wick drains are functional if the drainage layer is above the water table to enable drainage. The consolidation time in clay layers depends on several factors such as the distance between drains, driving depth, preload thickness, and stratigraphic characteristics. Fine sand intercalations are present in the ground, facilitating water drainage not only radially and horizontally but also vertically, favouring the design and application of the method.

6. CONCLUSIONS

In the Exodus-Fertisa project (Duran-Ecuador), geophysical prospecting campaigns were conducted using geoelectric tomography and electromagnetic sounding to evaluate the consolidation of soft clays. The applied improvement technique (preloading and wick drains) was found to have reliable control of the settlements and water table in the study area. Figures 7b show a layer of dry clays/silt (15-60 Ω-m) that is more appreciable than in Figure 7a, with a variable thickness of 1.00-1.25m.

Preloading is a widely used improvement method in various infrastructure projects; however, achieving the expected settlements takes a long time. The use of wick drains accelerates soil consolidation, allowing the settlement time to be drastically reduced by reducing the excess pore pressure in the soil. These soft clay improvement techniques permitted a 90% reduction in consolidation time (5-8 months), in addition to the expected settlements (0,09-0,10m).

In soil improvement techniques, constant monitoring is required to control the actual settlement performance and consolidation rates achieved by measuring the pore pressure dissipation over time, such as piezometers and settlement plates. These should be evaluated each time to ensure that the soil consolidates according to the planned time. This was verified by the calculated geophysical values (resistivities) and correlated with geotechnical values (void ratios).

Studying the correlations between the electrical parameter values obtained from geophysical testing is important because they present a less time-consuming alternative to conventional sampling methods. Correlations between electrical resistivity and consolidation-related parameters, such as void ratio, prove to be demanding because voids in the soil can be caused by air or water, and air acts as an insulator. In contrast, water contains ionised mineral salts that enhance the electrical conductivity of soil.

Through electromagnetic sounding and electrical tomographies carried out once the Fersal Aquaculture and Livestock warehouse was built, four predominant soil layers were differentiated on the site: clays of high plasticity with silt presence. These were compared with the parameters of the pre-construction soil, and an increase in resistivity was observed, which indicates that the consolidation process of the soil improved, resulting in an efficient preloading method with wick drains.

Therefore, using preloads and wick drains with the subsequent use of shallow foundations is a good option for projects with a predominance of soft clays that require almost immediate construction. However, despite improving the soil parameters, this method has limitations. Its effectiveness depends on factors that must be analysed and calculated analytically, such as the incidence of the depth of the water table, depth of installation of wick drains, distance between geosynthetics, thickness of preloading, and location of the drainage layer.

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CERTIFICACIÓN DE REVISIÓN DE PROYECTO DE TITULACIÓN

Por medio de la presente, Yo Davide Besenzon Venegas, Coordinador del Programa de Maestría en Geotecnia de la Escuela Superior Politécnica del Litoral (ESPOL), certifico que:

Con fecha 26 de enero de 2024, los estudiantes Wendy Abigail Cedeño Palacios y Josué Rolando Zumba Aguirre con números de identificación 0954463394 y 1205067638, respectivamente, de la Cohorte 5, presentaron la propuesta de su tema de titulación al Comité Académico del programa. Posteriormente, con fecha 22 de abril de 2024, el Comité revisó y aprobó la propuesta mediante la resolución FICT-CA-GEOTEC-005-2024, cumpliendo con los requisitos establecidos para la aprobación del tema.

A partir de dicha aprobación, los estudiantes mantuvieron reuniones periódicas con el tutor designado, Paúl César Carrión Mero, para la elaboración y desarrollo de su proyecto de titulación, siguiendo los lineamientos establecidos por el programa. Con fecha 08 de mayo de 2024, los estudiantes presentaron y sustentaron su proyecto de titulación ante el tribunal evaluador asignado, cumpliendo con el proceso formal de evaluación académica.

Por lo tanto, en calidad de Coordinador del Programa de Maestría en Geotecnia, certifico que el trabajo de titulación denominado **"Mejoramiento de suelo de arcilla blanda mediante precarga y wick drains. Proyecto Éxodo-FERTISA, Ecuador"**, realizado por los estudiantes Wendy Abigail Cedeño Palacios y Josué Rolando Zumba Aguirre con números de identificación 0954463394 y 1205067638, respectivamente, ha sido revisado y evaluado conforme a los lineamientos y estándares establecidos por el programa.

Debido a circunstancias externas, no ha sido posible obtener las firmas de los involucrados (estudiante, tutor(es) y/o evaluadores). No obstante, en calidad de Coordinador del Programa, certifico que el proyecto cumple con los requisitos académicos y ha sido revisado para su presentación y archivo institucional.

Atentamente,

Firmado electrónicamente por:
DAVIDE BESENZON
VENEGAS

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Coordinador de la Maestría en Geotecnia