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Geotechnical Zoning for the Construction of an Irrigation District in the Department of Atlántico - Colombia

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Abstract: For the construction of an irrigation district, the geotechnical conditions of the existing soils in the municipality of Ponedera (Atlántico, Colombia) were analyzed, by means of manual sampling and standard permeability test (SPT). This information was processed in a database for analysis. The soil types were obtained, most of which were classified as inorganic clays and silts (CL and ML), to a lesser extent, silty and clayey sands (SM and SC), and maps of soil types zoning and allowable capacity were drawn in GIS. No water table was found in the investigated soil area. Following the guidelines of the Colombian Earthquake Resistant Regulation (NSR-10) and the RAS, the usefulness for future studies has been concluded. Finally, the soil explored can support load capacities at a depth of 3.0 m of 31.8 ton/m^2.

Key words: zoning; geotechnics; types of soils; GIS

1. Introduction

Since the establishment of geotechnical engineering, it has been important for different activities of the programs and disciplines that require it. For many years it has provided support to different investigations that have been developed throughout the country.

According to the 2018 census, the population of Ponedera City in the Atlántico Province was 23,848.0 inhabitants, and projections for the year 2035 are around 30,201.0 inhabitants [1], which shows that there is little significant growth in the population, because there are few urban centers in the municipality and that the vast majority of its extension is of rural type where agriculture and livestock are practiced.

These agricultural and livestock practices require an irrigation system in most of their extension and due to the characteristics of the irrigation system, it is necessary to take into account standards such as the Technical Regulations of the Drinking Water and Basic Sanitation Sector (RAS) for the entire water distribution part and the NSR-10 for the complementary constructions of this system. For the above reasons, it is necessary to investigate the soil types that predominate there, since the execution of this type of project requires a broad knowledge of the soil and its bearing capacitiy.

It was considered of vital importance to perform the geotechnical incidence analysis in the entire area where the irrigation district will be built in the municipality of Ponedera, Atlántico Province. This was carried out by means of suitable tests for soil exploration according to the previously mentioned standards.

Therefore, in this article different geotechnical parameters such as soil type, soil profiles, admissible load capacity, cohesion and angle of internal friction according to the SUCs classification, were evaluated to determine their incidence in the execution of the irrigation district in Ponedera City of the Atlántico Province.

2. Materials and Methods

2.1 Study area

The research covers an area of 7731.25 hectares in the municipality of Ponedera, Atlántico Province, more precisely between the villages of Santa Rita and Puerto Giraldo.

Figure 1 shows the methodology followed for each of the stages of this research.

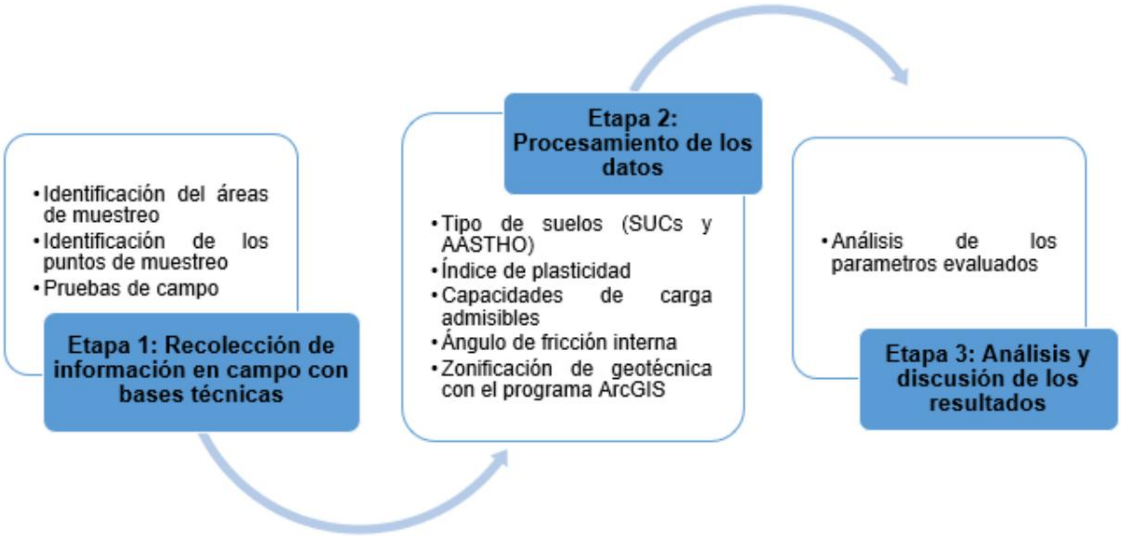


Figure 1. Stages of the methodology used

2.2 Study stages

2.2.1 Stage 1: Collection of field information on a technical basis

Identification of the sampling area: The sampling area was identified according to the size and magnitude of the irrigation system to be built in the municipality of Ponedera. This area was stipulated between the villages of Santa Rita and Puerto Giraldo delimited in Google Earth Pro.

Identification of the sampling points: Prior to determining the research area, the location of the sampling points for both the piles and the boreholes was determined, taking into account the location of the works that were planned to be carried out. Figures 2 and 3 show the location of the boreholes, which were distributed over the projected works, and Figure 4 shows the location of all the piles executed.

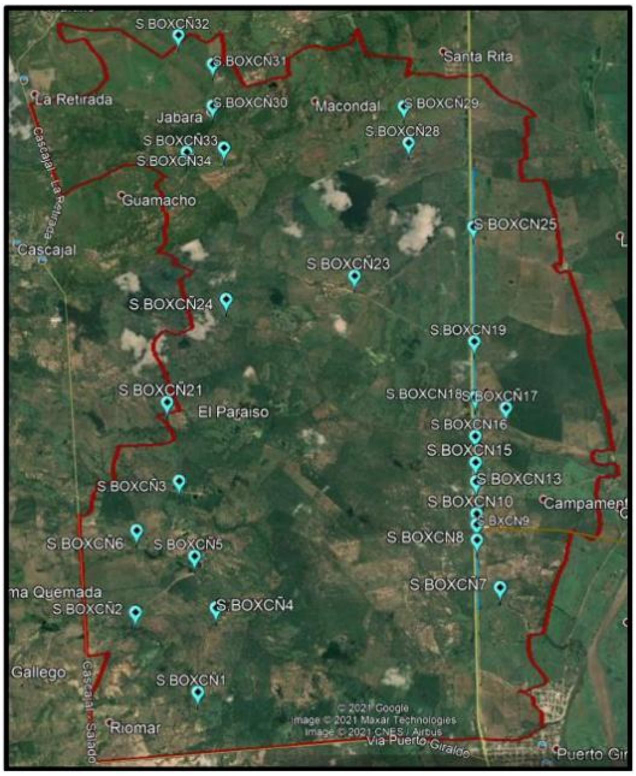


Figure 2. Location of measurement for small projects (box culvert)

Source: Google Earth

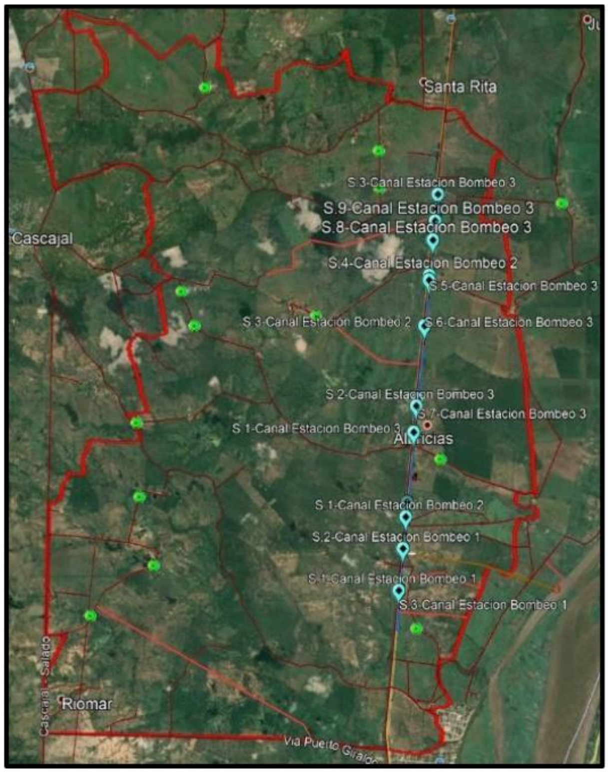


Figure 3. Location of the boreholes for major works (canals, sand trap and pumping stations)

Source: Google Earth

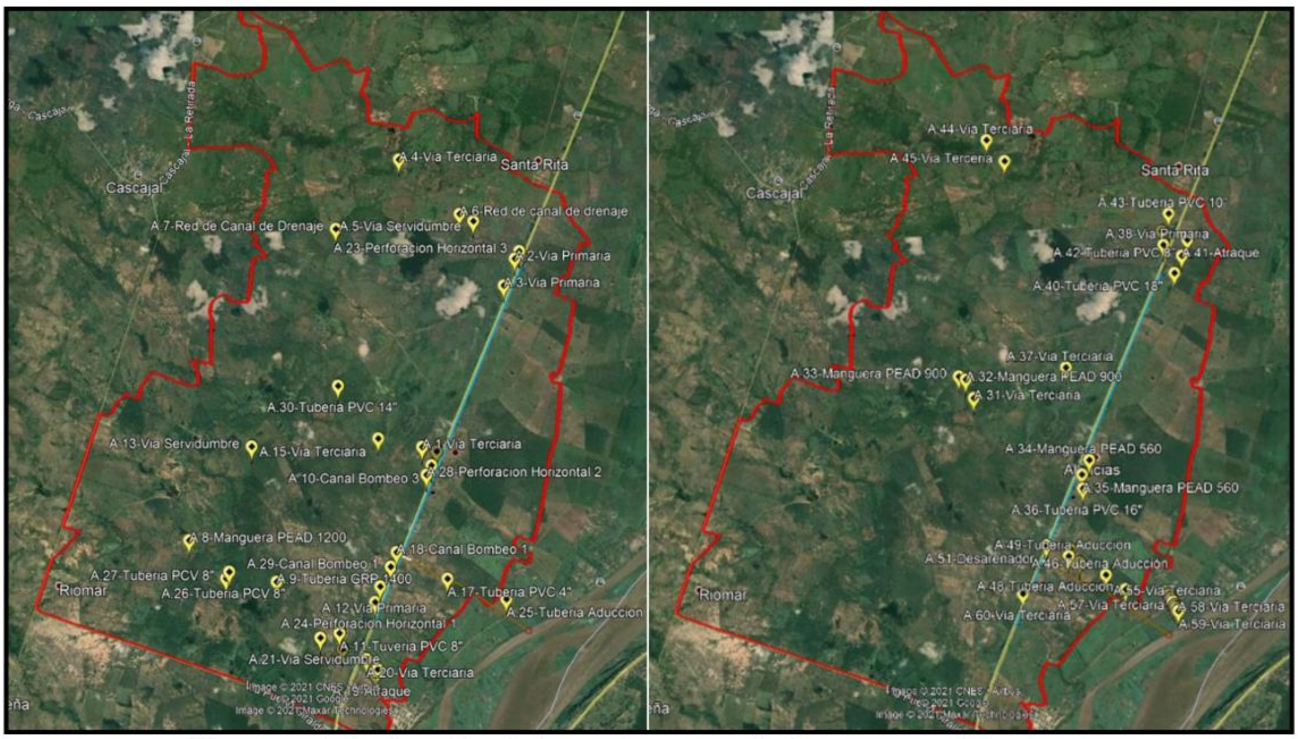


Figure 4. Location of the piles in different project areas

Source: Google earth

Field tests: The respective field tests were carried out with 79 piles at a depth of 2.0 m and 72 boreholes at depths between 2.0 to 6.0 m. From each test, a sufficient number of samples were taken to elaborate the following laboratory tests.

- Grain size analysis
- Soil classification in AASTHO and SUCs
- Calculation of admissible bearing capacity
- Angle of internal friction
- Determination of liquid limit
- Determination of plastic limit

One of the points where the water table was entered at a depth of 1.5 m was taken into account.

2.2.2 Stage 2: Data processing

In this stage, all the data obtained in the laboratory tests were processed, classifying the soils and their characteristics according to the results, as well as the creation of geotechnical zoning maps with ArcGIS software, resulting in the following maps:

- Soil type (SUCs and AASTHO)
- Plasticity index
- Permissible bearing capacities
- Internal friction angle

2.2.3 Stage 3: Analysis and discussion of results

Based on all laboratory tests conducted in the stage 1 and processed in the stage 2, and in accordance with the requirements mentioned in the above standards, the data processing results were analyzed, with a focus on the field of geotechnical engineering. The geotechnical characteristics of the soil under study were elaborated, such as type, internal friction angle, cohesion, bearing capacity, etc.

3. Results

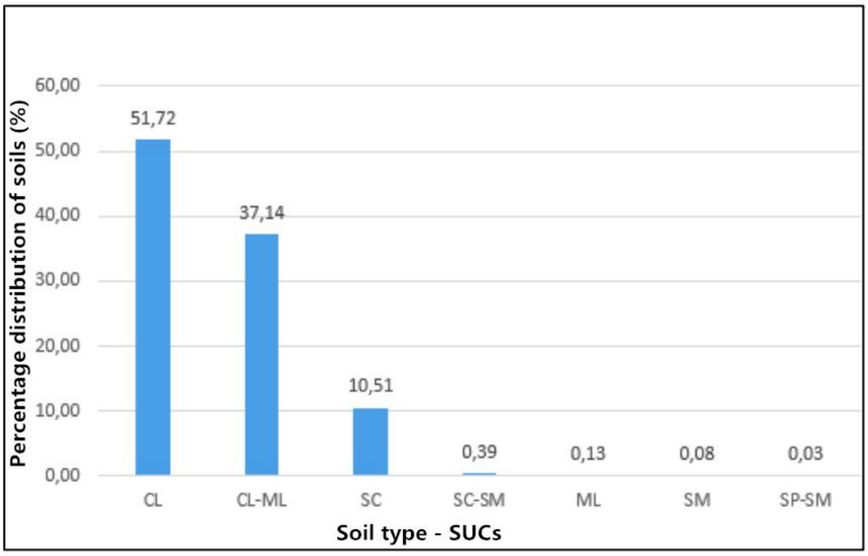
This chapter presents the analysis of the results obtained after the identification of the study areas, field exploration and laboratory tests, including particle size analysis tests, consistency limits (liquid limit, plastic limit and plasticity index) and direct cuts.

All these tests were necessary for the identification of the parameters in each identified area and the respective analysis and zoning of each one is presented below.

3.1 Soil type zoning in the area of the irrigation district project in the municipality of Ponedera, Atlántico Province

The area where the soil study was conducted is located in the municipality of Ponedera between the villages of Santa Rita and Puerto Giraldo.

Graph 1. Percentage distribution of soils in the irrigation district in the municipality of Ponedera according to the Unified Soil Classification System (SUCs)



The research area is 7731.25 hectares, mainly composed of CL type soil (low or medium plasticity inorganic clay, gravel clay, sandy clay, silty clay, and lean clay). Similarly, in the second case, according to the classification of the Unified Soil Classification System (SUCs), there are a large number of slightly plastic silty clay [3]. The predominant soil is inorganic clay (CL), accounting for 51.72% of the whole study area; while silty clay (CL-ML) accounts for 37.14%; the remaining percentage corresponds to types of soil made up of clayey and poorly graded sands. (Graph 1).

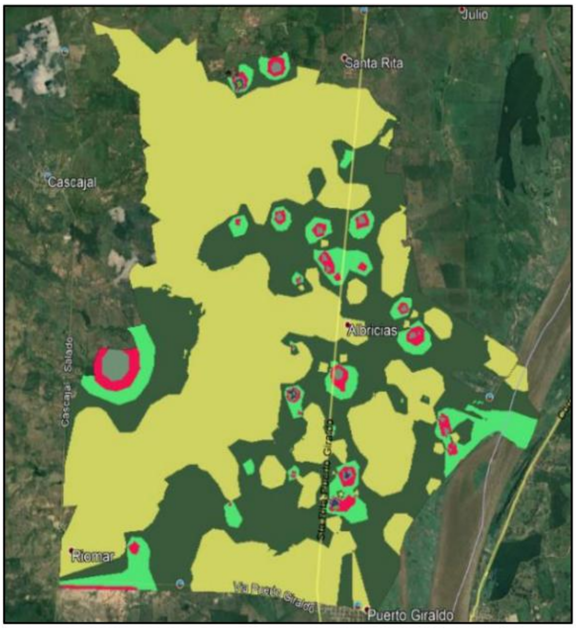
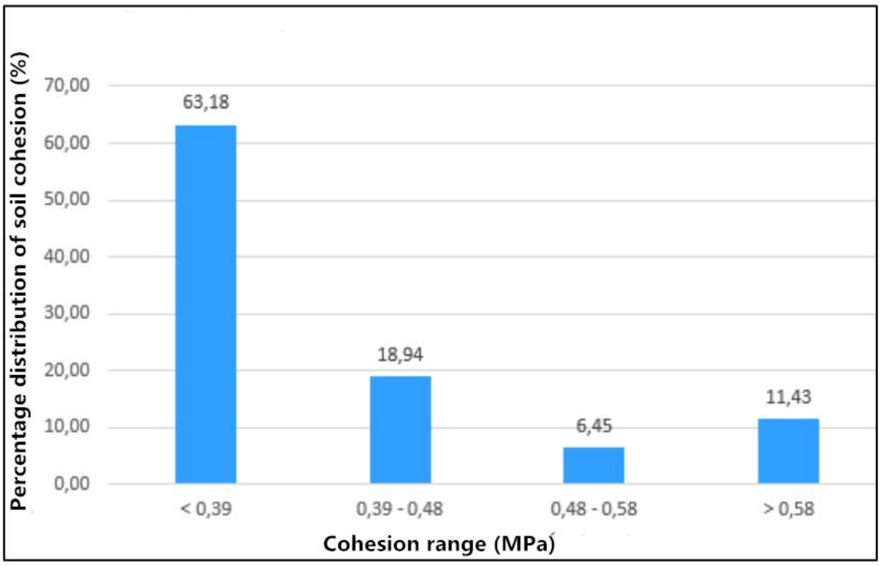


Figure 5. Soil distribution in the area directly affected by the project according to the Unified Soil Classification System (SUCs).

Source: Google Earth

3.2 Zoning of soil cohesion in the irrigation district in the municipality of Ponedera, Atlántico Province

Graph 2. Percentage distribution of soil cohesion in the area of direct influence of the project



In the direct impact area of the Ponedera irrigation district project, soil with different cohesion ranges can be found. Considering the total area of the area is 7731.25 hectares, the percentage distribution obtained is as follows: 63.18% of the total area is soil with cohesion below 0.39 MPa, and 18.94% is in the range of 0.39 MPa to 0.48 MPa, 6.45% are in a range of 0.48 MPa to 0.58 MPa and 11.43% exceed 0.58 MPa as evidenced in graph 2 and illustrated in figure 6.

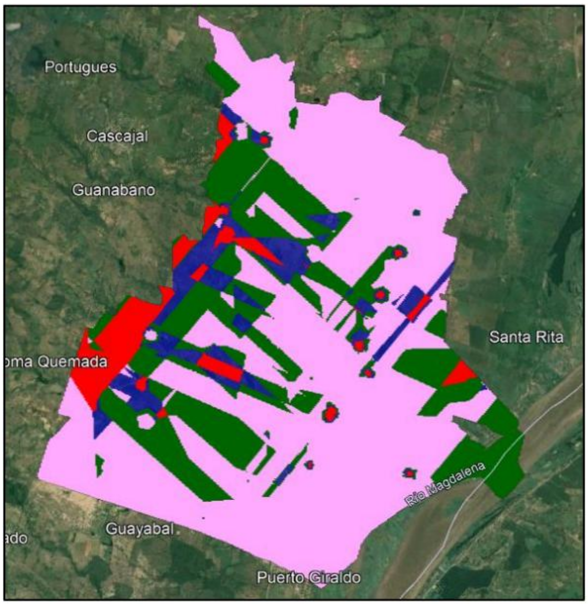
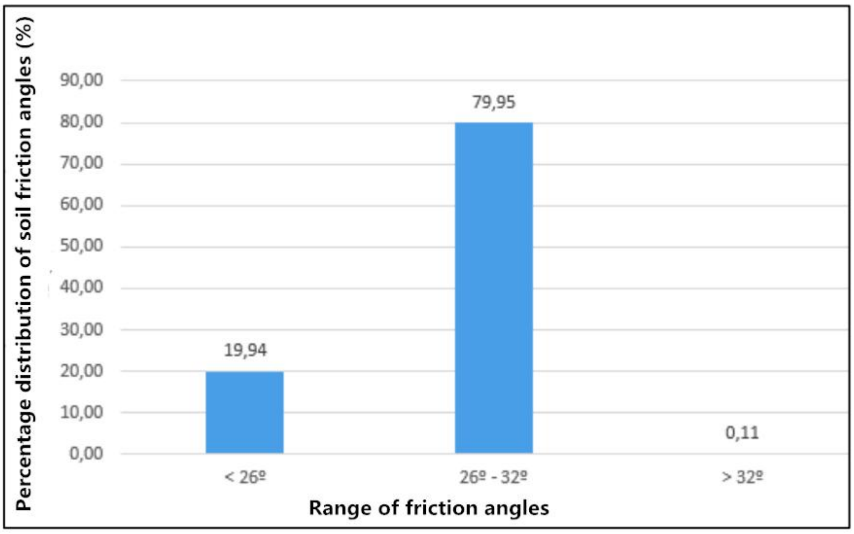


Figure 6. Distribution of soil cohesion in the area directly affected by the project.

Source: Google Earth

3.3 Zoning of friction angles of the soils present in the irrigation district in the municipality of Ponedera, Atlántico Province

Graph 3. Percentage distribution of soil friction angle in the area directly affected by the project.



Graph 3 shows the predominance of soils with a friction angle that can vary from 26º to 32º. However, this is not the only range shown by the results of the tests carried out, so the above mentioned graph and Figure 7 show the percentage of ranges lower than 26º and higher than 32º.

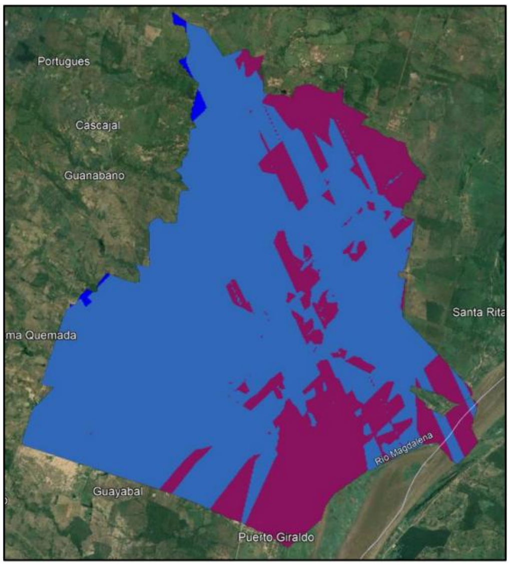


Figure 7. Distribution of soil friction angle in the area directly affected by the project.

Source: Google Earth

3.4 Load-bearing capacity

The bearing capacity of soil is defined as the pressure that the soil can withstand before the foundation failure occurs. To calculate the bearing capacity, it is necessary to have the geotechnical properties of the soil (cohesion and friction angle).

Taking into account the values obtained from the field and laboratory tests, the bearing capacities of the different zones at depths ranging from 1 to 2 m were calculated using Terzaghi's methodology, the results of which are shown in Table 1.

Table 1. Soil bearing capacity in the area directly affected by the project

Spot	Depth of displacement (m)	Permissible capacity (ton/m^2)
S.BOXCN1	2.00	17.6
S.BOXCN2	2.10	29.9
S.BOXCN3	1.65	16.4
S.BOXCN4	1.95	22.1
S.BOXCN5	2.00	24.6
S.BOXCN6	2.30	28.1
S.BOXCN7	2.80	18.8
S.BXCN8	1.30	21.2
S.BXCN9	1.20	8.70
S.BXCN10	0.90	9.80
S.BXCN13	1.10	9.00
S.BXCN15	1.50	5.00
S.BXCN16	2.80	31.8
S.BOXCN17	2.00	31.6
S.BXCN18	2.60	24.9
S.BXCN19	1.10	6.00
S.BOXCN21	2.50	26.1
S.BOXCN22	2.20	27.3
S.BOXCN23	2.30	16.4
S.BOXCN24	1.95	25.2
S.BXCN25	1.80	10.0
S.BOXCN28	1.60	15.6
S.BOXCN29	1.60	17.2
S.BOXCN30	1.60	16.5
S.BOXCN31	1.60	9.90
S.BOXCN32	1.60	24.9
S.BOXCN33	1.60	16.1
S.BOXCN34	1.60	13.4
S.SIF1	1.30	12.9
S.SIF2	1.00	8.10
S.SIF3	1.80	22.8
S.SIF4	1.00	7.10
S.1-Canal Pump Station 3	1.50	11.0
S.2-Canal Pump Station 3	1.50	12.0
S.31-Canal Pump Station 3	1.50	3.00
S.4-Canal Pump Station 3	1.50	7.00
S.5-Canal Pump Station 3	1.50	10.0
S.6-Canal Pump Station 3	1.50	12.0
S.7-Canal Pump Station 3	1.50	6.00
S.1-Tube. Adduction	1.50	8.10
S.2-Tube. Adduction	1.50	6.20
S.3-Tube. Adduction	1.50	6.70
S.4-Tube. Adduction	1.50	6.70
S.5-Tube. Adduction	1.50	6.20
S.6-Tube. Adduction	1.50	7.10
Pump Station 1	1.00	11.0
Pump Station 2	1.00	13.4
Pump Station 3	1.00	14.4
Desander	1.00	12.4
Berths	1.00	15.4
Offices	1.00	13.4

3.5 Standard penetration test (SPT)

The standard penetration test is used for geotechnical investigation of soil [4], because it can characterize granular soil (sand and gravel) and clay to understand the natural humidity of soil or other geotechnical conditions, such as soil profile type [5]. In this special case, the soil is divided into two types based on the impact frequency and shear wave velocity of the standard penetration test (SPT) [6]. As shown in table 2.

Table 2. Determination of soil profile types in the area directly affected by the project.

Spot	Vs (m/s)	nº of shock corrected	Profile type
S.BOXCN1	168	7	E
S.BOXCN2	238	19	D
S.BOXCN3	197	11	E
S.BOXCN4	219	15	D
S.BOXCN5	238	19	D
S.BOXCN6	229	17	D
S.BOXCN7	159	6	E
S.BXCN8	246	21	D
S.BXCN9	149	5	E
S.BXCN10	159	6	E
S.BXCN13	238	19	D
S.BXCN15	190	10	E
S.BXCN16	183	9	E
S.BOXCN17	265	26	D
S.BXCN18	159	6	E
S.BXCN19	203	12	E
S.BOXCN21	224	16	D
S.BOXCN22	242	20	D
S.BOXCN23	159	6	E
S.BOXCN24	238	19	D
S.BXCN25	242	20	D
S.BOXCN28	183	9	E
S.BOXCN29	176	8	E
S.BOXCN30	176	8	E
S.BOXCN31	138	4	E
S.BOXCN32	250	22	D
S.BOXCN33	197	11	E
S.BOXCN34	168	7	E
S.SIF1	159	6	E
S.SIF2	229	17	D
S.SIF3	149	5	E
S.SIF4	219	15	D
S.1-Canal Pump Station 3	258	24	D
S.2-Canal Pump Station 3	265	26	D
S.31-Canal Pump Station 3	168	7	E
S.4-Canal Pump Station 3	219	15	D
S.5-Canal Pump Station 3	242	20	D
S.6-Canal Pump Station 3	265	26	D
S.7-Canal Pump Station 3	208	13	E
S.1-Tube. Adduction	229	17	D
S.2-Tube. Adduction	208	13	E
S.3-Tube. Adduction	214	14	E
S.4-Tube. Adduction	214	14	E
S.5-Tube. Adduction	208	13	E
S.6-Tube. Adduction	219	15	D

Pump Station 1	183	9	E
Pump Station 2	183	9	E
Pump Station 3	242	20	D
Desander	219	15	D
Berths	219	15	D
Offices	183	9	E

4. Discussion of Results

Taking into account the zoning carried out in the project area covering 7731.25 hectares, it is observed that most of the soils present according to the SUCs soil classification are CL, representing inorganic clays of low to medium plasticity, clays with gravels, sandy clays, silty clays and lean clays [7]. In the few areas where materials with coarser particles such as poorly graded sands were identified, percentages of clay were also found, which corroborates that throughout the studied area the predominance of clays is constant. These soil types have impermeability characteristics and do not present drainage because it is a soil with fine particles; likewise, they are soils with good compaction and medium compressibility [8].

Regarding the cohesion characteristics, most of them are soils with cohesion values lower than 0.39 MPa, which coincides with the type of soil found, which were mostly inorganic clays of low to medium plasticity [8].

Due to the type of fine material, this characteristic exists throughout the exploration area, and the combination between particles provides conditions for the stability of the excavation. The situation of settlement is the opposite, because in cohesive soil, the probability of settlement exceeding the standard is higher, and if it is saturated soil, it will increase [9].

Similarly, it is observed that the predominance of friction angles is also in accordance with inorganic clays, being in a range between 26° and 32°. This parameter varies according to the plasticity of the material analyzed, since the higher the plasticity, the lower the friction angle [10].

It is also one of the most important parameters for the evaluation of the shear strength through which the bearing capacity of the soil was evaluated and calculated, also taking into account the cohesion of the soil [11]. These variables are important because there is a directly proportional relationship, since the greater the friction angle, the greater the allowable bearing capacity.

The final aspect of the study is the bearing capacity of soil with a maximum depth of 2.80 m [12], as the Terzagui model generates a bearing capacity of up to 31.8 ton/m^2 due to the cohesive soil and the aforementioned parameters.

5. Conclusion

Based on the particle size analysis results of each sample of materials that constitute the exploration area, it can be said that according to the Unified Classification System U.S. C [13], these soils are composed of SC, CL, ML, SM. According to the NSR-10 Soil Profile Classification, the soil profiles determined according to the found soil type are profile E and profile D.

79 piles were drilled with a depth of 2.0 meters, and 72 boreholes were drilled. The engineering conditions were low in complexity and the depth was shallow, making it impossible for most boreholes to reach a depth of 6.0 meters.

The project does not represent a major difficulty, since it is a low complexity project and with soil type 2, it has little variation and the excavations will not exceed 2.5 m for the most part. These excavation depths, number of piles and their separation, were taken according to the manual of the Agricultural Rural Planning Unit (UPRA) in its numeral 5.1.7.1.

Acknowledgments

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Conflicts of Interest

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

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