PRELIMINARY TESTS AND SOIL CHARACTERIZATION: A CASE STUDY ON THE CONSTRUCTION OF A FOOD INDUSTRY

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ABSTRACT

This paper explores the initial phases and processes involved in constructing a food industry in Divinópolis/MG, Brazil, focusing on a company supplying balanced meals. The study assesses the feasibility of construction, employing the civil engineering laboratory of UEMG/Campus Divinópolis for tasks such as topographical surveys and soil characterization. Various tests, including tactile-visual analysis, granulometry, Atterberg limit, U.S.C.S, HRB, and compaction, reveal a silty-clayey soil with low plasticity. These results support the selection of a direct footing foundation for the project. The importance of soil analysis before foundation decisions is emphasized, as it determines strength and composition predictability, crucial for load distribution. The paper also highlights the potential for soil liquefaction over time, underscoring the importance of anticipating future issues in soil-structure interaction.

KEYWORDS: *Soil study; Soil characterization; Soil classification; Soil-structure interaction.*

I. INTRODUCTION

The social and economic significance of civil construction in Brazil is evident primarily in its core objective of reducing housing deficits and simultaneously generating employment [1]. Despite the global impact of the COVID-19 pandemic in 2020 and the downturn in the sector, the Brazilian Chamber of the Construction Industry (CBIC) asserts that growth projections for 2021 will be the highest in 8 years, anticipating approximately 4% growth [2]. Another sector gaining momentum in

Brazil is healthy eating. As noted by França *et al*. [3], "healthy eating is a fundamental physiological need, influenced by cultural taboos, beliefs, and variations in social, ethnic, philosophical, religious, and regional contexts." The pandemic-induced emotional distress and heightened insecurity have led to increased consumption of ultra-processed foods. This excessive intake may contribute to the rise of various health issues, including obesity, metabolic syndrome, and cardiovascular diseases [4].

Considering this scenario, it becomes conceivable to envision the establishment of this enterprise - a company offering a diverse range of food options aimed at enhancing the quality of life for the population of Divinópolis/MG/Brazil and the surrounding region. The objective is to provide a nutritious diet through well-balanced, protein-packed meals, available for both wholesale and retail purchase in vacuum-sealed and frozen packaging, streamlining storage and consumption. As part of the current industry development, comprehensive studies are underway to assess the project's feasibility at the site, conduct a topographical survey for architectural planning, and perform soil studies for preliminary classification. These endeavour's aim to inform critical construction decisions, including the selection of an appropriate foundation type.

As per the terminology outlined in NBR 6502 (ABNT [5]), soil is essentially defined as a 'material resulting from the decomposition of rocks by the action of physical or chemical agents, with the potential inclusion of organic matter.' Given the diverse nature of rocks and their subsequent breakdown to create soil, the significance of soil investigation processes becomes evident. Analytical studies conducted by Alvim & Araújo *apud* Queiroz Neto [6], focusing on soils covered by various types of vegetation between Belo Horizonte/Minas Gerais/Brazil and Lagoa Santa Minas Gerais/Brazil, revealed the prevalence of *cerrado* in the most acidic and calcium-deprived soils. In general, these soils exhibited a clayey texture and were deficient in organic matter. Consequently, as emphasized by Aguiar [7], soil characterization plays a crucial role in evaluating its impact on building stability. Therefore, comprehensive assessments involving joint granulometry, Atterberg limits, compaction tests, along with Proctor and CBR classifications, converge to provide valuable insights for technical analysis. Stachera & Bet [8] emphasize the necessity of studying the soil's crucial geotechnical characteristics to create technical resources accessible to society. This is particularly vital for professionals in civil and environmental fields, enabling them to establish a foundation on safety, sustainable development, and economic considerations for effective project development and optimal solutions tailored to each soil type.

The objective of this study is to elucidate specific construction processes and their prerequisites for a project situated in Divinópolis/MG/Brazil. In essence, the research entails preliminary analyses and characterization tests conducted on the soil within the designated area for the food industry. All phases of this investigation were conducted through a combination of bibliographical and field research, adherence to contemporary standards on the subjects explored, compliance with legislation, examination of scientific articles, and related sources.

This paper is structured into sections that comprehensively address various aspects of the study. The Introduction contextualizes the problem, underscores its relevance, and outlines the research objectives. The Materials and Methods section details the stages of laboratory testing for soil samples, covering calculations relevant to soil characterization and granulometry. It also delves into the research limitations. The Results and Discussion section presents study findings, exploring the influence of the soil type on the choice of foundation for the project. This section provides graphs, tables, and a detailed analysis of soil-structure interaction. The conclusion succinctly summarizes the main results and discusses practical implications, recommendations based on the findings, and suggestions for future research.

II. THEORETICAL BASIS

Due to the inherent variability of soil or rock deposits, coupled with the spatial and temporal variations in the properties of these materials, engineering design poses significant challenges. Neglecting any factors influencing the design may lead to failures or necessitate building maintenance [9]. Hence, for precise technical applications reliant on parameters characterizing soil behavior, the execution of laboratory and field tests is indispensable [10].

The NBR 7181 (ABNT, [11]) establishes the particle size analysis test, designed to evaluate the distribution of grains in each soil sample. According to Sousa Pinto [12], particle size analysis typically comprises two phases: sieving and sedimentation. The weight of material passing through each sieve, expressed as a percentage of the dry weight of the sample, is denoted as the 'percentage that passes' and is graphically represented against the sieve opening on a logarithmic scale.

Alves *et al*. [33] highlight certain soil properties crucial for characterization, such as moisture, liquid limit (LL), and plasticity limit (LP). The LL is graphically correlated using pairs of values, plotting moisture content on the y-axis against the number of blows on a logarithmic scale on the x-axis. The LL represents the average moisture content above which the soil tends to exhibit liquid-like behavior [14]. The findings from this soil investigation aim to assist engineering professionals in making informed decisions regarding the construction aspects of large-scale projects, aligning with the study's objectives.

III. MATERIALS AND METHODS

3.1. General description of the project

The subject of this study is a food industry located in the municipality of Divinópolis/MG/Brazil, situated in block 128 within the Jardim Belvedere II district, bordered by Noé Soares, Erotides Gomes de Souza, Av. Paraná, and Gustavo de Melo Alvim streets. In accordance with Annex I of Law No. 2148, dated April 8, 2014, from the Divinópolis City Hall (Prefeitura Municipal de Divinópolis [35]), the food industry's location falls under the Multiple Use Zone (ZUM) classification, given its frontage facing Av. Paraná. The urbanized area selected for the development encompasses commercial buildings, educational and religious institutions, public facilities, recreational venues, and all necessary infrastructure for its operation. Figure 1 depicts the construction site and its surroundings. The total plot area is 7,184.70 m², with a perimeter of 347.85 m. However, only a portion of the plot, measuring 2,103.21 m² with a perimeter of 187.36 m, was utilized for the project.

The architectural design for the food industry comprises three single-story buildings: the administrative block, the industrial block, and the cafeteria block, illustrated in the floor plan presented in Figure 2.

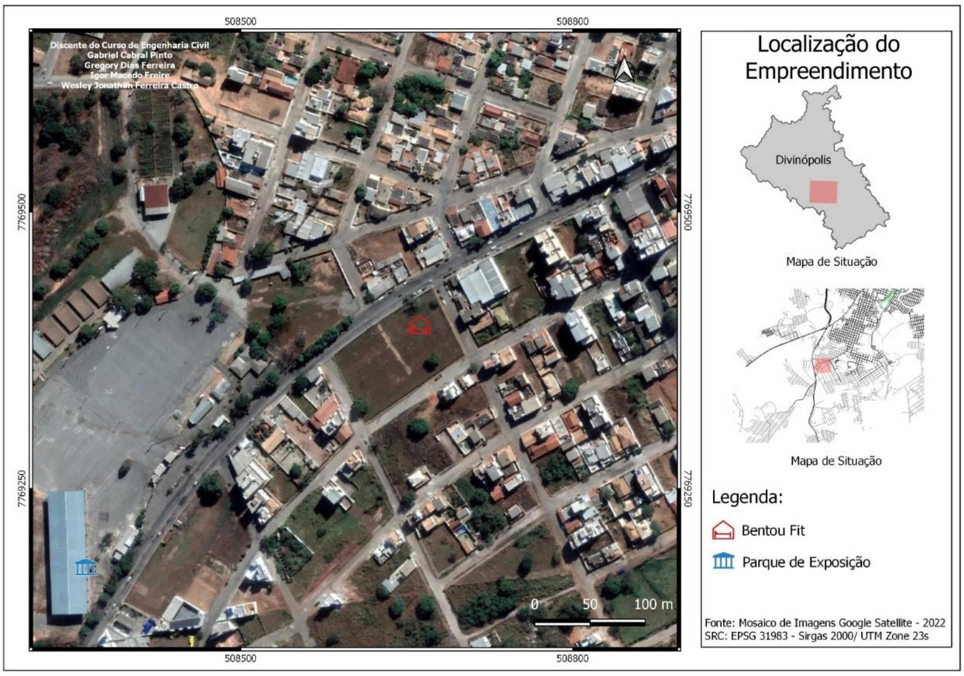

Figure 1. Location of the project's block

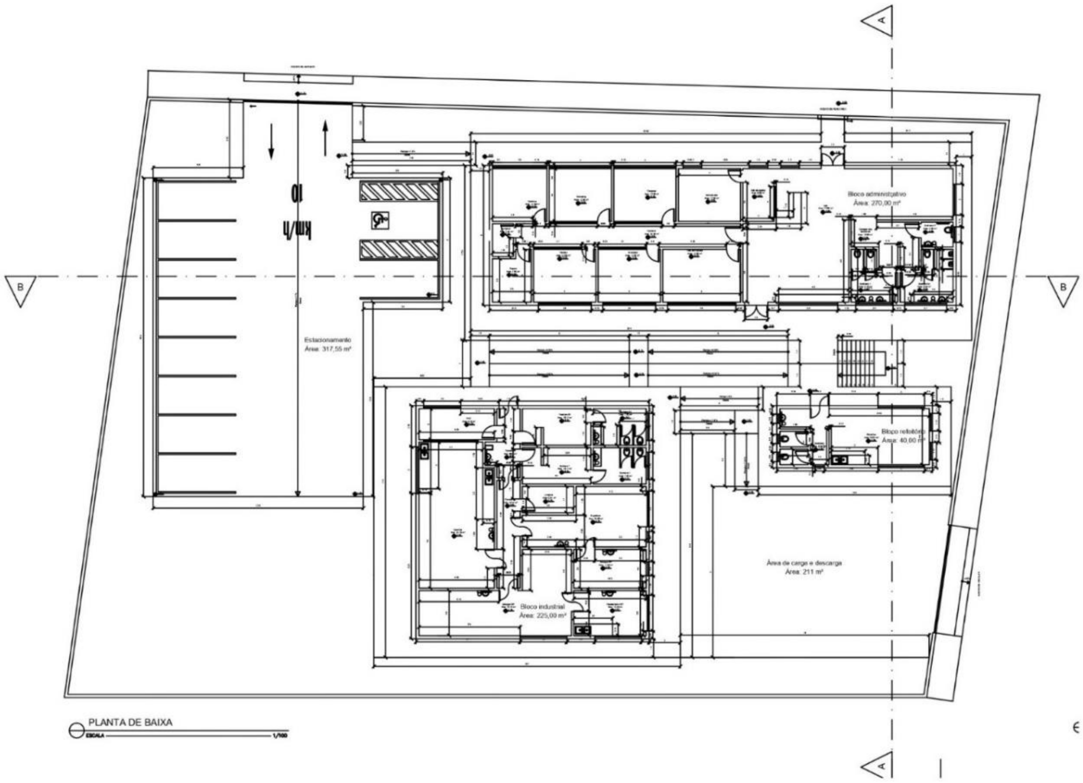

Figure 2. Floor plan of the project

The administrative block encompasses spaces for the company's administrative functions, a nutritionist's office, a sales area, a cafeteria, and three restrooms designated for customers and employees. Within the industrial block, designated areas cater to the receiving, handling, storage, and shipment of products and raw materials, including an industrial kitchen, control rooms, and restrooms with changing facilities. The canteen block consists of a single canteen and accompanying restrooms.

Beyond the three buildings, the project incorporates two paved areas: one for employee parking and another allocated for the loading and unloading of products and supplies. All structures within the project feature reinforced concrete frameworks, ceramic brick walls for sealing, and asphalt blankets for roof waterproofing. Emphasizing the importance of lighting during the design phase, a substantial number of windows and glass walls were incorporated to maximize natural light utilization. To achieve a modern design and adhere to health and hygiene standards, metal doors and frames were employed across all blocks. Figure 3 serves as a reference for the vertical plane, displaying the development's façade, along with transverse and longitudinal profiles of the terrain. Figure 4 shows the sections AA and BB, where the main vertical dimensions and the foundation projection are observed.

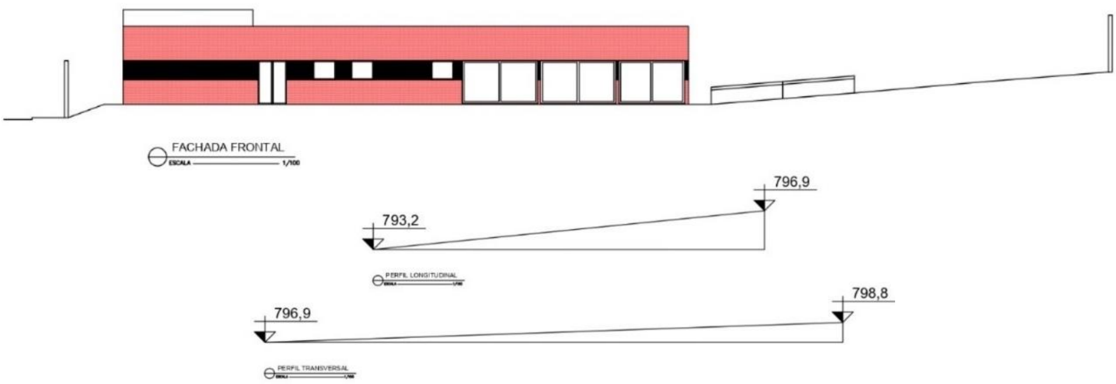

Figure 3. Frontal facade and longitudinal and transverse profiles

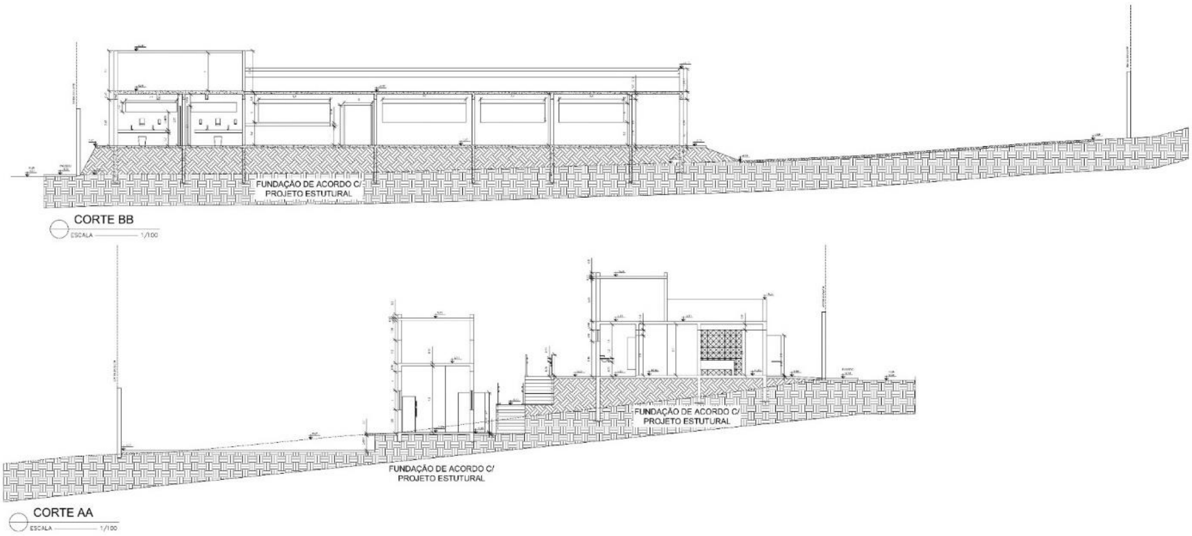

Figure 4. Section's AA & BB

3.2. Topographic survey

Topography enables the determination of the elevation difference between two points, regardless of the distance separating them, and provides insights into the earth's volume that needs to be either removed (cut) or added (filled) to transform initially uneven land into a flat surface, suitable for constructing a building or any desired purpose [14].

The surveying method employed on the development site involves closed polygonal walking and irradiation. The procedures outlined in NBR 13133 (ABNT [15]) were adhered to for conducting the survey.

As per NBR 13133 (ABNT [15]), a comprehensive topographic survey encompasses planning phases, including the selection of methods and equipment, determination of necessary topographic support, surveying site details, calculations and adjustments, generation of the final topographic drawing, and the preparation of a technical report containing all collected information.

For this topographic survey, a BERGER DGT10 theodolite manufactured by CST was utilized, featuring an angular precision of five seconds (5"), along with a graduated ruler, tape measure, markers for polygon vertices, calculator, and a field notebook.

The walking method involves traversing the contour of the polygon, initiating from a designated point and returning to it. The angles and distances of the polygon's sides are measured to establish a closed polygon. In contrast, the irradiation method entails keeping the theodolite fixed at a point and capturing multiple views at specific locations, intending to later calculate the plot's unevenness, with a chosen clockwise direction.

For the topographic survey of the area, four wooden pickets are strategically placed within the study plot, named stations 1, 2, 3, and 4. The criterion for selecting these points involves aiming at the previous station (RÉ) and aiming at the next station (VANTE) at the picket installation locations.

Simultaneously with the topographic survey of the closed polygon, various points are collected, including corners and trees on the land. The irradiation method is employed for this purpose, with data collected at each of the four positioned pickets. Data collection involves positioning the graduated ruler and reading stadimeter wires, vertical and horizontal angles, and the equipment's height. Filling in the field notebook requires incorporating the obtained sight data, and calculations are performed using Equations 1 and 2:

$$DH = 100 \,.\, M \,.\, \cos(2Z) \tag{1}$$

$$DV = \frac{100 \,.\, M \,.\, \sin(2Z)}{2} - FM + I \tag{2}$$

Where: DH represents the horizontal distance between two points (in meters), M is the range of readings on the staff (calculated as the difference between the stadimeter wires divided by 2), Z is the vertical angle (obtained by subtracting the zenith angle read from 90°), FM is the mean stadimeter wire, and I is the height of the optical canter of the telescope relative to the station's topographic point (in meters).

Using the collected and recorded data in the field notebook, it becomes possible to locate trees and determine the contour lines of the entire terrain. After obtaining the distances between the points, the closure of the polygonal is measured, along with the errors in surveying distances and the polygonal, facilitating necessary adjustments through data correction.

With this corrected data, along with the aid of AutoCAD (2021) software with the TopoCAD extension, all ground-collected points, including the polygon and trees, are drawn, and located. Subsequently, it becomes feasible to calculate the size of each side of the plot, its area, and the contour lines of the land. Figure 5 illustrates the final topographic survey of the studied land.

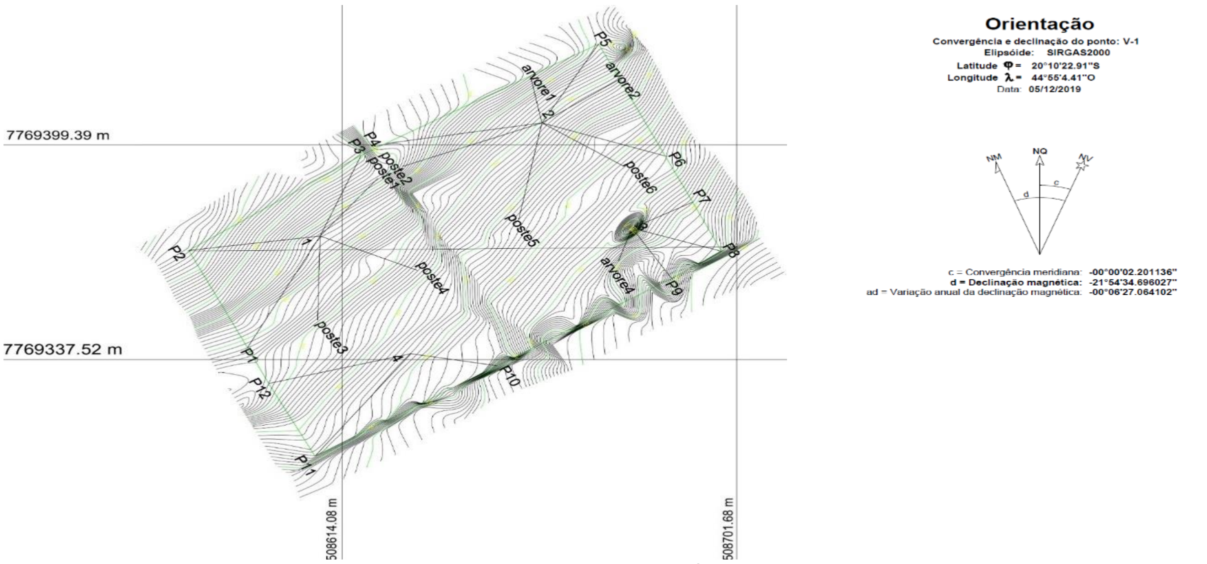

Figure 5. Topographic survey of the project site

3.3. Contour lines

Contour lines are lines plotted on a map, connecting various points at the same elevation. These lines result from the topographic survey of a specific area or study region, enabling the creation of maps that depict the elevation variations in the surveyed location.

As per NBR 13133 (ABNT, [15]), the topographic representation of the terrain may involve contour lines complemented with measured points, contour lines alone, or solely measured points, depending on the survey's purpose and the characteristics of the terrain.

Understanding the terrain is the pivotal starting point for all projects, and extra attention at this stage can be the key to ensuring a swift and trouble-free construction process, from land grading to the completion of all construction phases. For the land where the project is situated, contour lines with their elevations are generated, as illustrated in Figure 5.

3.4 Cut and fill volume

According to the architectural design and planimetric information obtained in the topography phase, it is possible to determine where there should be excavation or filling of the terrain. Taken from the terrain profiles used to identify the cut and fill areas shown in Figure 3, it is noted that the profiles are spaced 20 meters apart. Some intermediate profiles with distances less than 20 meters are established, where the distance from the previous profile is indicated in the marking of the succeeding profile.

With the cut and fill areas determined, Table 1 is prepared with the cut and fill volumes. This table aims to optimize the earthwork of the development. Therefore, upon completing this stage, a final positive volume is obtained, indicating the amount of soil that is disposed of.

To calculate the corrected volume, it is necessary to apply a soil swell factor, as loose soil occupies more space than when naturally compacted. For the determination of the swell factor, the values established by Mattos [34], Table 2, are considered, and the adopted soil type is common soil with up to 25% swelling.

Figure 6 indicates the accumulated volume according to the established stakes. In the end, it is possible to determine that for the excavation of the terrain, a volume of 789.68 m³ of soil needs to be removed, of which 387.84 m³ is used for backfilling, resulting in a volume of 401.84 m³ of soil that is discarded. The final disposal is the responsibility of an outsourced company hired for this service.

Table 1. Cut and fill volume of soil

Pile	Areas		Volume			Transverse length	Longitudinal length	Cumulative volume
	Cut	Fill	Cut	Fill	Corrected			
V-0	0	0	0	0	0	0	0	0
V-0+13	5.099	0	33.14	0	0	0	33.14	33.14
V-1	2.48	0	26.53	0	0	0	26.53	59.68
V-1+6,5	27.807	5.52	98.44	17.97	22.46	22.46	75.98	135.66
V-2	24.111	9.95	350.45	104.48	130.60	130.60	219.85	355.51
V-2+12,5	13.042	12.56	232.21	140.71	175.89	175.89	56.32	411.83
V-3	0	0	48.91	47.12	48.91	48.91	-9.99	401.84

Table 2. Soil blister factor

Material	Soil swelling (E)
Blasted rock	50%
Clay soil	40%
Common earth	25%
Dry sandy soil	12%

Source: Mattos [34]

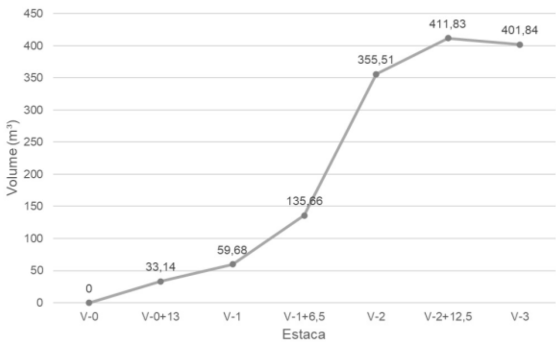

Figure 6. Accumulated soil volume

IV. RESULTS AND DISCUSSION

4.1. Soil study

Soil is a material resulting from the decomposition of rocks, exhibiting diverse characteristics such as color, particle composition (clay, silt, and sand), fertility, and porosity, which vary based on their origin [16]. In civil construction, soil is frequently utilized, necessitating comprehensive studies on its sustainability and resistance properties to determine appropriate use and occupation [17].

To use soil effectively, understanding its characteristics is crucial to prevent issues like landslides, floods, or other disasters related to soil alterations, thereby minimizing environmental damage. In line with NBR 6457 (ABNT [18]), a thorough analysis of the soil at the study site involves conducting characterization tests. Samples are collected from the land intended for development, and the initial step is to place these samples in an oven at 105ºC for 24 hours. Subsequently, as illustrated in Figure 7, the samples are ground to avoid grain breakage and ensure sample homogenization.

Figure 7. Soil disaggregation

4.2. Tactile-visual analysis

The first test for the study and initial soil classification attempt is conducted preliminarily through a simple analysis, known as tactile-visual. This analysis involves examining the soil by touch and sight, subjecting it to basic tests to assess initial reference values. In this context, processes such as the jar test (providing a preliminary value for soil composition) and exudation test, among others, are performed [19]. The classification results can be observed in Table 3.

While this test is considered simple and relies solely on the sensitivity of the performer to interpret the results, which may introduce considerable errors, it is often employed in the field or in small-scale projects where detailed soil studies have not been conducted. In such cases, preliminary identification of local soil without the use of laboratory equipment becomes a practical option [20]. During this initial investigation, it was observed that the soil at the site exhibits characteristics indicative of a clayey soil. Souza Pinto [12] notes that clayey soil tends to feature distinctive fine-grain particles, and its classification is determined not only by the clay content but also by its activity and consistency.

Table 3. Results obtained through tactile-visual inspection of the soil.

Test	Results	Characterization
Particle size	Large presence of silt and clay	Clay-silt soil or silty-clay soil
Gloss	Very shiny surfaces	Clay soil
Feel/Texture	Fine texture and moldable when wet	Silty-clay soil
Ball drop	The ball spreads less and with greater cohesion	Clay soil
Glass	% sand = 41.17%; % silt = 29.41%; clay = 29.42%	Clay soil
String	The ball could only be broken with a lot of effort	Soil with a lot of clay
Tape	Long, it was possible to form a ribbon of more than 25 cm without difficulty	Soil with a lot of clay
Exudation	No difference could be seen with more than 30 blows	Soil with clay
Dry strength	High resistance and does not spray	Inorganic soil, clay
Roll	Broke at less than 80mm	Not enough clay for ideal rammed earth construction

4.3. Granulometry test

Another conducted test is the granulometry test, which aims to construct the granulometric curve by analyzing the dimensions of soil grains and the proportions within the collected sample. The test classification and methods adhere to the guidelines specified in NBR 7182 (ABNT, [21]). The equipment employed for the test includes #4, #10, #40, #80, and #200 sieves, as stipulated by NBR NM ISO 3310-2 (ABNT [22]), along with scales, mortar, a grating hand, a sieve shaker, a Bunsen burner, capsules, and spatulas. For this test, 1 kg of soil is utilized, and all procedures recommended by NBR 6457 (ABNT [18]) are meticulously followed. The sample undergoes 15 minutes of vibration in a soil vibrator, passing through sieves with different mesh sizes, as illustrated in Figure 8. The soil shaker is organized from the sieve with the largest mesh to the smallest, concluding with the bottom where the portion of soil smaller than the last sieve is collected.

Following the separation of the soil sample that has passed through each sieve, two 10g samples are extracted from the soil retained in the #10 sieve. These small samples are subjected to heating using a Bunsen burner, enabling the calculation of soil moisture (h%) based on Equation 3. The obtained results are presented in Table 4.

$$h\% = (P_t - P_s)/P_s . 100 \quad (3)$$

in which: h% is the hygroscopic moisture of the material passed through the 2.0mm sieve; Pt is the total weight (in g) and Ps is the weight of the dry soil (in g).

Figure 8. Soil vibrator.

Table 4. Soil moisture per sample

Amostra	h%	P_s (g)	P_t (g)
1	6.15	9.421	10
2	5.20	9.506	10

After determining the average soil moisture, the total mass of the sample can be calculated using Equation 4, and the percentage of material passing through each sieve can be determined with Equation 5. The results are then tabulated in Table 5, serving as the foundation for plotting the particle size curve depicted in Figure 9. This curve represents the cumulative passing percentage (on the abscissa axis) against the sieve diameter in millimetres (on the ordinate axis).

$$M_s = \frac{M_t - M_g}{100 + h\%} . 100 + M_g \quad (4)$$

where: Ms is the total mass of the dry sample (in g); Mt is the mass of the dry sample (in g); Mg is the mass of the dry material removed from the 2.0mm sieve (in g); and h% is the hygroscopic moisture of the material passing through the 2.0mm sieve.

$$Q_s = \frac{M_s - M_i}{M_s} . 100 \quad (5)$$

where: Qs is the percentage of material passing through each sieve; Ms is the total mass of the dry sample (in g); and Mi is the mass of the accumulated dry material retained on each sieve (in g).

Table 5. Granulometry test

Sieve	Mesh (mm)	Weight (g)	Passed (%)	Retained	Accumulated (%)
4	4.750	1	99.900	0.100	99.900
10	2.00	21	97.899	2.101	97.799
40	0.420	407	59.277	40.723	57.076
80	0.177	277	72.285	27.715	29.361
200	0.074	182	81.790	18.210	11.151
Bottom	0	112	0	11.151	0

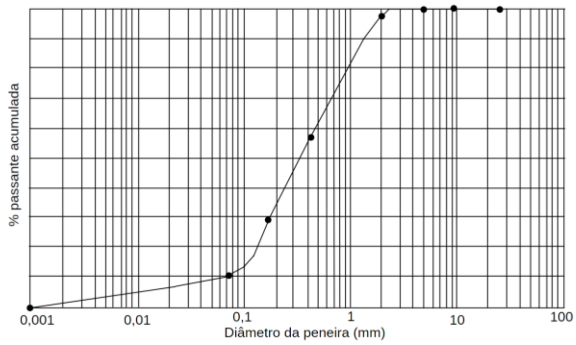

Figure 9. Particle size curve

The subsequent step involves determining the coefficients of uniformity (Cu) and curvature (Cc). This is achieved by intersecting the percentage and diameter at points D10%, D30%, and D60%. The calculated values are 0.0581818, 0.1829268, and 0.4615385, respectively. The uniformity coefficient (Cu) is then computed using Equation 6, and its classification is as follows: Cu ≤ 5 = very uniform; 5 < Cu ≤ 15 = moderately uniform; Cu > 15 = non-uniform.

$$C_u = \frac{D_{60\%}}{D_{10\%}} \tag{6}$$

The curvature coefficient (Cc) can be found using Equation 7 and its classification is as follows: 1 ≤ Ce ≥ 3 = Well graded; 1 > Ce or Ce > 3 = Poorly graded.

$$C_e = \frac{(D_{30\%})^2}{D_{60\%}.D_{10\%}} \tag{7}$$

The granulometry test classifies the soil as sandy, with 89% of the sample composed of sandy particles and only 11% consisting of fine particles. The calculated coefficients are as follows: the coefficient of uniformity (Cu = 7.93) classifies it as a moderately uniform soil, falling within the range of 5 to 15, while the coefficient of curvature (Cc = 1.25) categorizes it as a well-graded soil, as it falls between 1 and 3.

4.4. Atterberg limit

According to Das & Sobhan [23], soil behavior is contingent upon its moisture content, leading to classification as solid, semi-solid, plastic, or even liquid. To determine this classification, it is essential to identify the Atterberg limits, which establish intervals defining the soil's consistency, thus establishing Liquidity Limits (LL) and Plasticity Limits (LP) (SOUZA *et al.*,[24]). Tests for Atterberg limits are conducted following the guidelines of NBR 6459 (ABNT, [25]) and NBR 7180 (ABNT, [26]). The required materials include a grating hand, mortar, scale, metal tray, sieve no. 40, Casagrande apparatus, chisel, capsules, spatulas, and an oven. To determine LL, a soil sample retained on the No. 40 sieve is dried and mixed with distilled water in a porcelain container until a homogeneous mass is achieved, as depicted in Figure 10. The resulting mass is then transferred to the Casagrande apparatus, where a cut is made with a chisel through an opening no more than 10mm thick, and the mass is struck at intervals of 6 to 35 blows until the crack is closed. This process is repeated three times with increasing amounts of water.

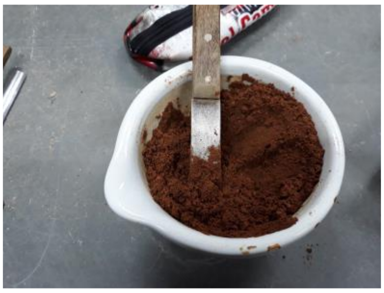

Figure 10. Homogenization of the sample

The LL calculations are made using Equation 8, but it is necessary to first define the soil moisture value using Equation 3. The results of the moisture content of the samples can be seen in Table 6 In view of this, the liquidity limit found for the soil is 41.9%, as can be seen in Table 7.

$$L_L = \frac{h\%}{1{,}419 - 0{,}3.\,log\,N} \tag{8}$$

where: LL is the liquidity limit; N is the number of blows; and h% is the moisture content of the soil (in %).

Table 6. Soil moisture content

Capsules	**1**	**2**	**3**
Total weight	24.313	25.377	24.791
Dry weight	17.590	17.902	17.190
h%	38.221	41.755	44.218

Table 7. Liquidity limit

Capsules	**1**	**2**	**3**
Soil+Tare+Water	34.360	35.423	34.681
Soil+Tare	27.907	27.948	27.080
Tare	10.317	10.046	9.890
No. of blows	30	27	26
Liquidity limit	39.166	42.194	44.462
Average Liquidity Limit		41.941	

To determine the Plasticity Limit (LP), a 10g sample is taken, and distilled water is gradually added until a homogeneous paste is achieved. This paste is then shaped into a ball and further molded into a cylinder through hand movements on a flat surface. The cylinder is considered to have reached the Plasticity Limit when it breaks with a diameter of 3mm and a length of 100mm. For accurate results, the procedure is repeated three times, and the average soil moisture values are calculated using Equation 3. The average soil moisture content, denoted as LP, is found to be 36.1%, as indicated in Table 8.

Table 8. Plasticity Limit

Capsules	**4**	**5**	**6**
Soil+Tare+Water	11.295	12.100	11.541
Soil+Tare	10.922	11.718	11.103
Tare	9.827	10.422	9.859
Total weight	1.468	1.678	1.682
Dry weight	1.095	1.206	1.244
h%	34.064	39.138	35.209
Plasticity limit		36.137	

Using the LL and LP data, the Plasticity Index (PI) can be determined. As Fiori [27] notes, PI tends to be higher in clay soils and lower in sandy soils due to the presence of clay minerals and their absence in sands. The Plasticity Index is calculated as the difference between LL and LP and is categorized as follows: $1 < LP \leq 7$ = Weakly Plastic; $7 < LP \leq 15$ = Medium Plastic; $LP > 15$ = Highly Plastic.

In the current study, the soil is classified as weakly plastic, with a percentage of 5.804%. Contrary to the general trend mentioned by Souza, Raful, & Vieira [24], where a higher percentage of clay fraction usually increases the influence on the determination of LL, the soil under investigation exhibits the opposite behavior. This discrepancy can be attributed to the predominant presence of sand grains in the soil.

4.5. U.S.C.S Classification

The Unification Soil Classification System (U.S.C.S) involves identifying soil types using a combination of two letters. Among these, the top five letters on the chart indicate the primary soil type, while the remaining four letters provide additional complementary data for the soil [28]. When classifying soil within the category of fine soils, the CasaGrande Plasticity Chart is employed, considering only the LL and IP values.

Most of the studied soil is categorized as sand, with grain sizes exceeding 0.074mm in diameter, as detailed in section 4.3. The LL and IP values are plotted on the CasaGrande Plasticity Chart, as illustrated in Figure 11. Notably, with an IP of 5.804% and LL of 41.941%, the soil is identified as ML or CL. These designations characterize silt-clay soils with low plasticity or lean clays—both exhibiting low compressibility, minimal cohesion, and high permeability, according to DNIT [29].

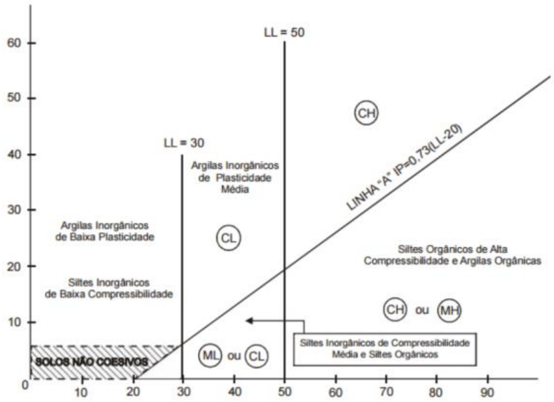

Figure 11. Casagrande Plasticity Chart

4.6. HRB classification

The Highway Research Board (HRB) classification system is a method used to classify soils into eight groups (A-1 to A-8), based on granulometry, with some subdivisions for better soil separation. To carry out the classification, it is necessary to use the Group Index (GI), Equation 9, which can be defined as: "[...] an integer with a range between 0 and 20 that is a function of the percentage of material that passes the No. 200 sieve and the index properties (LL and IP) [...]" [30].

$$\mathrm{IG} = (0{,}2.\mathrm{a})(0{,}05.\mathrm{a.c}) + (0{,}01.\mathrm{b.d}) \tag{9}$$

Where: IG for the group index; a, representing the percentage passing the No. 200 sieve minus 35%, ranging from 0 to 40; b, denoting the percentage passing the No. 200 sieve minus 15%, with values from 0 to 40; c, indicating a liquidity limit value less than 40%, ranging from 0 to 20; and d, the plasticity index minus 10%, with values between 0 and 20.

Based on this formula, the soil in the study is classified using the Soil Classification: HRB Suggestion table recommended by the American Association of State Highway and Transportation Officials (AASHTO) (DNIT, [29]). It is identified as an A2-5 Soil or Silty Sand Soil, predominantly composed of boulders and silty or clayey sands, making it well-suited for subgrade use. This classification results from the sample's primary constituent being pebbles or silty-clayey sands, with granular materials constituting 35% or less passing the No. 200 sieve. The overall analysis consistently indicates silt-clay characteristics for the soil at the site.

4.7. Compaction test

Soil compaction is a process influenced by mechanical force, resulting in reduced porosity, increased shear strength, and consequently, decreased compressibility and permeability, as explained by Bueno & Vilar [31].

This compaction process is better understood when considering the influence of interstitial water on soil particles. When wet, particles slide, adopting a more compact arrangement, restricting the expulsion of air from pores (Klein, Madalosso, & Baseggio, [32]).

The Normal Proctor test, detailed in NBR 7182 (ABN, [21]), establishes a method for determining the relationship between moisture content and the dry apparent specific mass of compacted soil. To conduct the test, a 15kg soil sample is collected from various points on the study site (Figure 12). Testing materials include a mechanical sample extractor, mortar, grating hand, No. 4 sieve, scale, cylinder mold, socket, capsules, steel ruler, steel spatulas, specimen extractor, and an oven. After collection, soil moisture is removed using ovens, and the soil is then sieved with a No. 4 sieve to eliminate pebbles mixed in the sample.

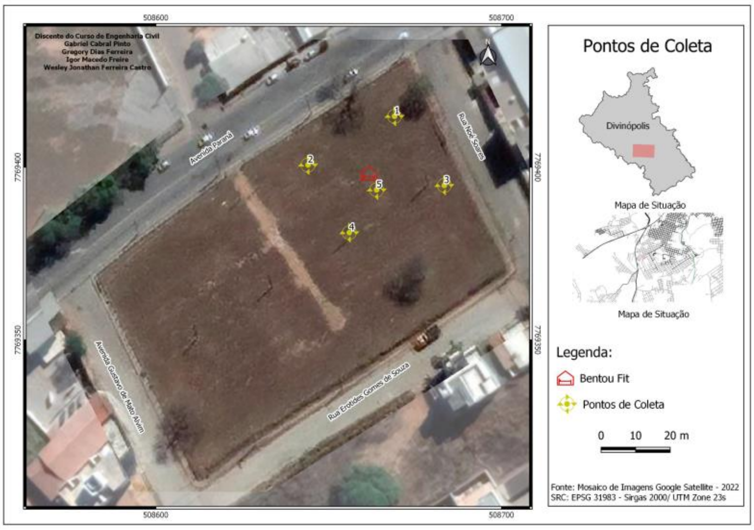

Figure 12. Soil sampling points

After crushing the soil, it is divided into five smaller samples, each weighing 3 kg. Various amounts of water are added to individual samples and mixed until homogenized. Subsequently, the moisture content of each sample is determined using Equation 3, with the results presented in Table 9. Remarkably, the consistency of the results across samples taken from different ground points indicates the homogeneity of the soil. Figure 13 illustrates key stages of the laboratory compaction test.

Table 9. Soil Moisture Content

Moisture determination				**Hygroscopy**	
Capsule				1	11
Capsule weight + moist soil (g)				17.114	16.129
Capsule weight + Dry soil (g)				17.024	16.051
Weight of water (g)				0.090	0.078
Capsule weight (g)				5.928	7.810
Weight of dry soil (g)				11.096	8.241
Moisture content (%)				0.810	0.950
Average				0.88	
Humidity adopted	17.69	19.37	21.05	22.740	24.420
Apparent Dry Density (g/cm³)	1.566	1.617	1.672	1.619	1.581

a) b) c) d) e)

Figure 13. Photo collection of laboratory tests. (a) Cylinder. (b) Arranging the soil in the cylinder. (c) Compacting the soil with the socket. (d) Removing excess soil. (e) Sample extractor.

Each sample is then placed in cylinders with a volume of approximately 1000 cm³, as depicted in Figure 13a. The samples are arranged in three layers, each containing an equal amount of soil (Figure 13b). A socket administers up to 26 blows to each layer (Figure 13c). Subsequently, excess soil is removed from the cylinders (Figure 13d), and the specimens are extracted using an extractor (Figure 13e) to facilitate the weighing of the cylinders and the analysis of soil consistency.

These specimens allow for the determination of apparent dry mass (Equation 10) and compaction moisture (Equation 11). The results are presented in Table 10 and are also illustrated on the apparent density graph shown in Figure 14.

$$P_{\delta} = \frac{M_u.100}{V(100.W)} \quad (10)$$

Where: P_{δ} is the bulk density (g/cm³); M_u is the wet mass of the compacted soil (g); V is the effective volume of the cylindrical mold (cm³); W is the moisture content of the compacted soil (%).

$$P_d = \frac{S}{\frac{W}{P_W} + \frac{S}{P_s}} \quad (11)$$

Where: P_d is the dry bulk density (g/cm³); W is the moisture content, chosen within the range of interest (%); P_s is the specific gravity of the soil grains (g/cm³); P_w is the specific gravity of water (g/cm³).

Table 10. Compaction Results

Cylinder no.	6	2	6	2	6
Water added (ml)	500	550	600	650	700
Cylinder weight + Moist soil (g)	4110	4220	4285	4275	4230
Cylinder weight (g)	2330	2355	2330	2355	2330
Weight of moist soil (g)	1780	1865	1955	1920	1900
Cylinder volume (cm³)	966.040	966.040	966.040	966.040	966.040
Apparent wet density (g/cm³)	1.843	1.931	2.024	1.987	1.967

The results of the Normal Proctor test enable the adjustment of soil void indices to enhance resistance against settlement in the area. The maximum dry density is determined as 1.672 g/cm³, with an optimum moisture content of up to 21.11%. These values align with literature recommendations. According to Klein, Madalosso & Baseggio [32], the test outcome is crucial for establishing the appropriate water content in compacted soil samples, preventing potential technical issues, and influencing the selection of a structural scheme through soil-structure interaction.

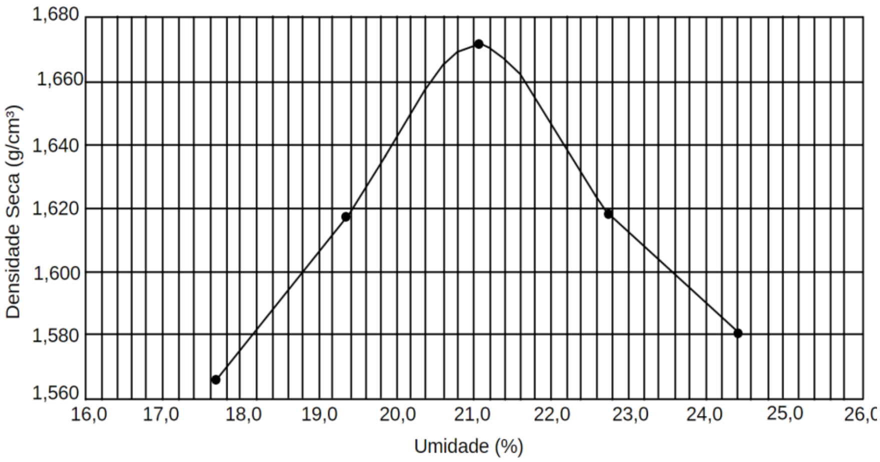

Figure 14. Apparent density graph

V. Conclusions

Through the stages outlined in this study, starting with the overall project description, it is possible to examine the processes involved in constructing a food industry, as determined at the study's outset. It is emphasized that these stages adhere to technical standards and current legislation in Brazil, aiming to ensure quality and safety throughout all phases.

Concerning the topographic survey, it enables the analysis of the terrain's contour lines, facilitating the precise development of the architectural project. This includes determining the specific land characteristics and actions necessary for project implementation, such as required cuts and fills. This project's development allows for the conception of a facility meeting all current standards for safety, quality, accessibility, among other requirements.

In the soil study, characterizing it through various tests like tactile-visual analysis and compaction tests is crucial. The results of these tests, along with the borehole report, provide essential technical information for selecting the most suitable technical solution for the project. In this case study, the choice of foundation in the structural design phase is based on the results obtained during soil characterization. For the soil of the project's land, classified as low plasticity silty-clay, a shallow foundation type - specifically, a footing - is adopted, recommended for soils with low coherence and mechanical behavior intermediate between sand and clay. Regarding execution, the initial step involves excavating the trenches, followed by compacting the base and finally casting lean concrete. Subsequently, the positioning of molds, reinforcement at the base, and pillar reinforcement is carried out, following structural design recommendations. After these steps, the footings are cast, with mold removal occurring after the concrete has hardened. The last step involves curing the concrete.

The study, through laboratory tests, highlights the soil's sensitivity, demonstrating that the probability of cross-sectional liquefaction increases over the life span of the structural project. These results provide valuable information for a precise assessment and effective mitigation of the liquefaction risk. Therefore, through these tests, a review of literary works, theoretical concepts on the subject, and the case study evaluation, practical know-how is established to assist civil engineering professionals in the construction of large-scale projects or similar buildings.

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