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Relationship of Field Capacity with Geotechnical Parameters in an Urban Solid Waste Landfill

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Abstract

One of the main environmental problems of landfills of urban solid waste is the release of leachate which can result in soil and water contamination. Leachate represents one of several risk factors for the environment, since it has high concentrations of polluting agents. The possibility of knowledge about the leachate generation is important for the evaluation of the efficiency of a treatment system, as well as the knowledge of the soil and waste field capacity is also essential to implement a control of the total moisture content in the landfill that influences biodegradation and methane production. The objective of this work was to evaluate the use of an efficient method of obtaining the field capacity for the layer of grounded solid waste cover, relating them to several geotechnical parameters. The obtaining of the field capacity of the soil and the residues consisted of driving the sampling cylinder through a backhoe, statically driving the small Shelbys (10.4 to 11.8 cm in diameter by 20 cm in height) to obtain the samples. In the laboratory, the samples had their ends sawn to remove excess waste, where they were then placed in a large bucket with a gravel mat, approximately 15 cm, to facilitate the saturation of the sample by the hydrostatic process of vessels communicants, where, after reaching saturation, they were placed in free drainage conditions in order to reach field capacity. The tests indicated that the average field capacity for the soils was 35%; for new wastes values varying from 43 to 56% and for old wastes values of volumetric field capacity ranging from 30 to 44%. Thus, it was observed that many empirical models used in dimensioning leachate treatment plants do not take into account a variable that directly influences leachate production.

Keywords: Moisture; Soil; Waste; Leachate; Sizing.

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1. Introduction

Brazil has Law 12,305 of 2010, which deals with the National Solid Waste Policy (PNRS) with the premise of a national strategy designed to promote the extinction of dumps and sustainable development in the area of solid waste, such as improved treatment, collection and final destination of residues, with the purpose of solving environmental, economic and social problems arising from the reality of inadequate disposal still so present in the country [1]. Landfills are sanitary engineering works, where they are destined to receive solid urban waste. These landfills are created and designed to minimize the impacts caused by waste on the environment in a technically adequate and environmentally correct way. At the end of the useful life of depositing solid waste from a landfill, it does not discontinue the complex processes of biodegradation of waste inside the cells since the landfills continue to generate gases and leachate [2]. Obtaining geotechnical parameters for solid urban waste (MSW) is essential for the preparation and execution of landfills. The knowledge of the field capacity of the covering layer and the residues are of great importance, since they interfere in the water balance of the sanitary landfill and, consequently, in the dimensioning of the drainage and leachate treatment systems [3,4]. The possibility of knowing the leachate production range is important for the evaluation of the collection and treatment system of this effluent in landfills, where these systems must meet the volume of liquid produced in the landfill and what passes through the mass of Waste, in order to guarantee the preservation of surface waters and groundwater. The objective of this work is to use an efficient method of obtaining the field capacity for the landfill covering layer and the landfilled waste, relating them to various geotechnical parameters. With the determination of these parameters, it is possible to estimate the amount of leachate to be generated in landfills using the soil and waste field capacity, in addition to comparing the values obtained with other existing empirical models.

2. Materials and Methods

This section is divided into three parts. The first is a brief history of the Aterro da Muribeca (Jaboatão dos Guararapes, Pernambuco, Brazil). The second part presents the methods used to obtain the field capacity of the landfill and waste cover layer as well as other geotechnical variables analyzed in this study.

2.1. History

The landfill is in the rural area of Jaboatão dos Guararapes, in the locality of Muribeca dos Guararapes, near the Integration Hub in Prazeres - Jaboatão, about 16 km from the center of Recife. The layout area is among the following coordinates: 280,000 to 282,000 East and 9,096,000 to 9,098,000 North, occupying a total area of 60 hectares, with a perimeter of 3,848 meters. It was the largest landfill in operation in the state of Pernambuco, receiving around 2,400 tons of regular solids (household waste), bulky solids (scraps and scrapings) and pruning residues by July 2009. The average gravimetric composition of the landfill, based on secondary data: 46.3% of organic matter; 12.2% paper / cardboard; 19.4% plastic; 1.9% metal; 2.7% wood; 3.5% of textile materials; 0.8% rubber and leather; 1% glass; 3.6% of disposable diapers; 6% coconut and 2.6% others [5]. The closure of the Aterro da Muribeca occurred in July 2009, as it was characterized by the Public Prosecutor's Office as an inadequate form of disposal of municipal solid waste. In this same period, besides the prohibition of the entrance of new residues, the recovery of this landfill began, realizing the total coverage of the plateaus and the planting of native species of the Atlantic Forest in the whole area.

2.2. Determination of Soil and Waste Moisture

This step consisted of the monthly collection, of soil and Waste, in capsules, where they were later weighed and placed in an oven (Model Orion 515 by Fanem) at a temperature of 105ºC, according to guidance [6]. The purpose of this collection was to obtain the necessary data for the empirical model based on field capacity. In addition to the moisture in the mass and volume bases, another convenient way of expressing the water content in the soil is through the water depth depth. This way of expressing the moisture content is very useful, because it becomes compatible with the way of expressing the amount of water used in various phenomena. For example: water that is precipitated by rain or irrigation is measured in terms of blade (cm or mm). The water lost from the soil and the plant through evaporation and transpiration is expressed in blade per unit time (mm / day, cm / month, cm / year, etc.).

$$L = \theta_v \cdot h \qquad (1)$$

Where: L = Water blade for depth "h" to soil (mm ou cm)

h = depht (mm ou cm)

θv = Volumetric humidity (%)

θm = Bulk moisture (%)

The moisture content, on the basis of mass, was calculated as follows:

$$\theta m\% = \left(\frac{\text{Wet weight} - \text{Dry weight}}{\text{Dry weight}}\right) x100 \qquad (2)$$

The moisture content, on the volumetric basis, was calculated based on the mass moisture:

$$\theta\% = \frac{(\theta_m \cdot dp)}{(1+e)} x100 \qquad (3)$$

Where:

e = voids index;

dp = density of particles or grains;

θv = Volumetric humidity (%);

θm = Mass humidity (%).

2.3. Determination of Specific Weight of Soil and Waste (γ)

It followed the norm [7] where the determination of the specific wet weight, both for the soil and the Waste, consisted of the ratio between the weight and volume of the sample taken by Shelby. The dry specific weight was obtained through a calculation based on humidity and wet specific weight, as presented by equation 4.

$$\gamma s = \frac{\gamma h}{1+h} \quad (4)$$

Where:

γs = Dry specific weight (g / cm3);

γh = Wet specific weight (g / cm3);

h = Humidity of the waste.

2.4. Determination of Porosity of Soil and Waste

It is the relationship between the void volume and the total volume, and is also related to the void index. It is worth mentioning that the void index is the relationship between the void volume and the volume of solid particles.

$$n = \frac{e}{1+e} \quad (5)$$

Where:

η = porosity of the soil or Waste;

e = index of voids in the soil or waste;

$$e = \frac{\gamma g}{\gamma s} - 1 \quad (6)$$

Where:

e = index of voids in the soil or waste;

γg = specific weight of soil particles or waste (g/cm^3);

For the soil: 2,66 g/cm^3;

For waste: 2,27 g/cm^3, according to [8];

γs = specific weight of the soil or waste (g/cm^3).

2.5. Soil Particle Analysis

In a soil, variations of different sizes usually coexist. It is not always easy to identify how to separate the grains of sand, for example, it may be surrounded by a large amount of clay, very fine, shows the same aspect of agglomeration that is used only by these clays. When dry, as two formations are hardly differentiated. When wet, however, an agglomeration of transformed clays becomes a fine paste, while a sandy particle is easily used by the rough. Therefore, to tactilely - visually identify the grains of a soil, it is essential that it finds it very moist. According to [9], for a recognition of the size of a soil, perform a granulometric analysis, which consists of two parts: Sieving and Sedimentation. Sieving is used to separate differences that vary above 0.074 mm, that is, color differences. This selection is due to the use of sieves of different sizes, where it is possible to analyze different soil types. Sedimentation is used when the soil is thin, with dimensions less than 0.074 mm.

a) Screening of Coarse Soil

The coarse material that is retained in the sieve 10 is washed (on top of the same sieve) by water jet, to remove all the soil present in these grains. The rest of the sieve is taken to the greenhouse for 24 hours. After drying, it is necessary to weigh the dry sample. A weight P of a dry soil sample is taken and sieved; then, the weights of the portions retained in the various sieves are taken (varying numbers), expressed as percentages of the total weight:

$$\text{That is: } \left(\frac{P1}{P}\right)x100, \left(\frac{P2}{P}\right)x100, \left(\frac{P3}{P}\right)x100, \ldots \qquad (7)$$

Adding these percentages, we have the “retained percentages” and taking the complement to 100 we have the “accumulated percentages that pass”. Thus, $100 - \left[\left(\frac{P1}{P}\right)x100\right]$ it is the percentage that passes through the first sieve; $100 - \left\{\left[\left(\frac{P1}{P}\right) + \left(\frac{P2}{P}\right)\right]x100\right\}$ is the accumulated percentage that passes through the second sieve, and so on. Then, all the percentages retained from the coarse soil that were used to build the grain size curve are obtained.

b) Fine Soil Sedimentation

A quantity of soil was taken and passed through the sieve 10 and dispersed in water, which was added, for better dispersion of the elements, a deflocculant (sodium hexametaphosphate). The soil was left to rest, where the solution acted for 24 h. Then, the entire solution was placed in a 1000 cm^3 beaker and completed with distilled water. The cylinder was placed in a constant temperature and environment. The mixture was stirred inside the cylinder for 1 minute and a decimeter, previously tared, was introduced, reading its gradual sinking on the gradation after 30 s, 1 min, 2 min, 4 min, 8 min, 15 min , 30 min, 1 h, 2 h, 4 h, 8 h, 25 h, from the moment the test tube was immobilized. At the end of this process, all the material that was in the beaker was washed with a water jet in the number 200 sieve. The washed material went to the oven, where it was dried for 24 h. Then, the same screening procedure was used for coarse soils, with difference only in the sieve openings

2.6. Determination of Soil Consistency Limits

Grain size alone is not enough to classify soils with a texture rich in fine particles. Its plastic properties depend on the moisture content, with which the different soil states are defined. Thus, the main characteristic that allows the identification of clay soils is plasticity, defined as the property of a soil, in a humid state, which will undergo great deformations without suffering rupture.

2.6.1. Determination of Soil Liquidity Limit

The Liquidity Limit (LL), according to [10] of the soil, is the moisture content for which the groove closes with 25 strokes. The Liquidity Limit is determined by the Casagrande apparatus, which consists of a brass plate, in the shape of a shell, on an ebonite support; by means of an eccentric, drops of height of 1 cm and constant intensity were repeatedly printed on the plate. With the obtained values (number of strokes to close the groove made in the sample) the flow line of the material is drawn, which, in the interval between 6 and 35 strokes, can be considered as a straight line. The determination of 6 points is recommended.

2.6.2. Determination of the Plasticity Limit of Soils

According to [11] the Plasticity Limit (LP) is determined by calculating the percentage of moisture by which the soil started to fracture when trying to mold a cylinder 3mm in diameter and about 10 cm in length. After the test, the sample was weighed on a sensitive precision analytical balance and the material was taken to the oven for 24 hours to have a constant weight (established humidity).

2.7. Determination of Matrix Suction by Filter Paper

According to [12], the method consists of placing a filter paper, with known retention characteristics, in an airtight container, along with a soil sample. Upon reaching equilibrium, the moisture potential in the paper will be obtained, which is equal to the soil moisture potential. To obtain total suction, the filter paper is placed dry in an airtight container, in direct contact with the soil. In this case, the balance between the suction of the soil and the paper is achieved through the vapor phase. Matrix suction was obtained using Whatman No. 42 filter paper, where it allows suction measurements from zero to 29 MPa. For this test, the following materials and equipment were used:

- Analytical balance with a minimum accuracy of 0.0005g.
- PVC film and aluminum foil to avoid loss of moisture from the samples.
- Styrofoam box for isolating samples.
- Tweezers and scissors.
- Greenhouse (105ºC).
- Whatman Filter Paper No. 42.

According to [13], one of the most important aspects to obtain an adequate suction measurement is to ensure that the filter paper, after equilibration, is removed from the equilibrium environment without significant loss of moisture. The moisture loss can be of the order of 1.5% per minute for a humidity of approximately 35%, where it will depend on the moisture of the paper. For low humidity (high suction) evaporation is less. When removed from the oven, the paper absorbs water from the air and therefore must be quickly placed in the container and sealed. The equations used for calibration were:

- For humidity higher than 47%:

$$Suction\ (KPa) = 10^{(6{,}05-2{,}48x\ log\ w)} \qquad (8)$$

- For humidity less than or equal to 47%:

$$Suction\ (KPa) = 10^{(4{,}84-0{,}0622w)} \qquad (9)$$

For a precise characterization of the Characteristic Curve, a model based on the equation of [14] will be used, where the following equation is used:

$$\frac{\theta-\theta r}{\theta s-\theta r} = \left(\frac{1}{1+(\alpha\psi)^n}\right)^m \qquad (10)$$

□s = Saturated volumetric moisture content, which is the minimum moisture content that makes the soil saturated.

□r = Residual volumetric moisture content, which is the moisture content where a large increase in suction is required to remove water from the soil.

□ = relates to air intake suction

m and n = are related to the slope of the characteristic curve after the air intake.

□= matrix suction.

In this research, studies were carried out regarding matrix suction, which is related to the energy state of the water interacted with the solid particles of the soil, that is, everything that refers to the capillarity and adsorption phenomena. These phenomena depend on the porous arrangement, distribution of pores according to their average diameter, surface tension of the water, affinity between water and solid surfaces, among others. The method used to obtain the Characteristic Curve was the Filter Paper through drying (Figure 1). A [14] calibration model was used to obtain an accurate curve.

Figure 1: Data collection procedures: (A) Weighing the filter paper on an analytical balance using tweezers (B) Filter paper placed for drying in an oven at 105ºC to obtain moisture (C) Weighing the ring + ground.

2.8. Determination of Soil Field Capacity

The procedure of this test consisted of driving sampling cylinders over regularized soil (waste cover layer), using a backhoe, where, soon after, the samples were sent to the laboratory to obtain the field capacity from soil. In fact, obtaining the sample in the field consisted of driving the Shelby (thin-walled samplers with a diameter ranging from 10.8 to 11.4 cm and height between 40 and 50 cm) on a level layer of soil. A steel plate was used over Shelby to prevent further damage to samples and samplers. The driving was done statically with the hydraulic pressure of the backhoe shovel, as seen in Figure 2. At the end of the sampling, it was dug around the cylinder and carefully removed with the aid of a hoe. In the laboratory, the five samples had their ends sawn off to remove excess soil. Then, they were placed in a large bucket with a gravel mat, approximately 15 cm, to facilitate sample saturation (Figure 3a). Through the hydrostatic process of communicating vessels, saturation began. The sample was saturated when, on its surface, water was present, as seen in Figure 3b. After the sample is saturated, the water retained in the soil can drain freely. On average, for sandy soils, drainage occurs between 3 to 4 days. For clayey and silty soils, around 5 to 6 days. It is worth mentioning that a plastic film is placed over the samplers to avoid the loss of moisture to the environment. Once the drainage period has ended (observing that there is no water on the sample surface), the sample from the intermediate layer is taken to the greenhouse to obtain moisture in the field capacity (Figure 3b).

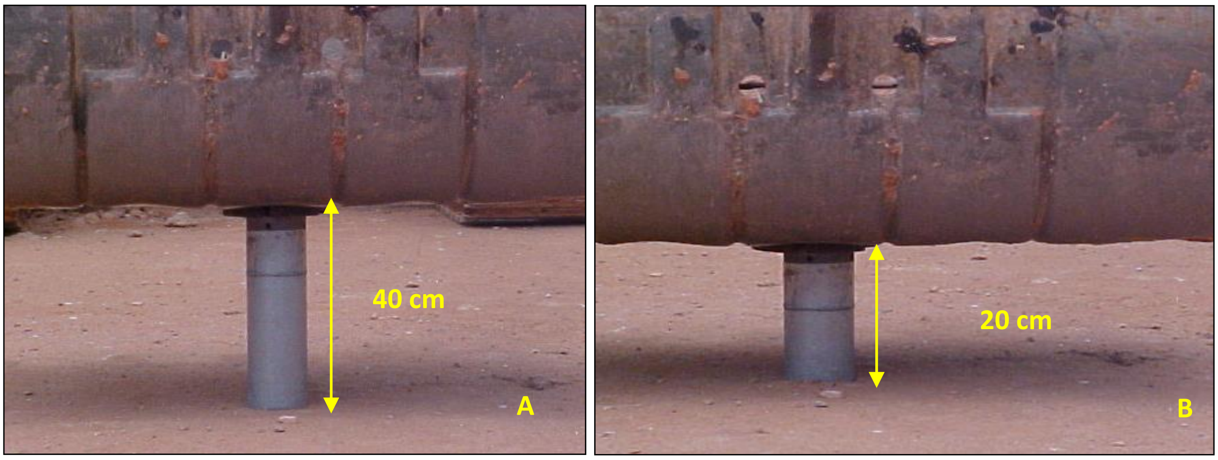

Figure 2: Static setting of Shelby in the Waste cover layer.

Figure 3: Laboratory analysis. (A) Soil saturation through the process of communicating vessels. (B) After completely drained, the sample is placed in the oven.

2.9. Waste Field Capacity

The test procedure was like that of the ground. It consisted of driving the sampling cylinder over the level trash. With a backhoe, the small Shelby (10.4 to 11.8 cm in diameter by 20 cm in height) are statically attached to obtain the Waste sample. A steel plate was used over Shelby to prevent further damage to samples and samplers. The driving was static, with the hydraulic pressure of the backhoe shovel, as shown in Figure 4. At the end of the sampling, dig around the cylinder and remove it carefully, with the help of a hoe. In the laboratory, the six samples had their ends sawn off to remove excess waste. Then, they were placed in a large bucket with a gravel mat, approximately 15 cm, to facilitate the saturation of the sample by the hydrostatic process of communicating vessels. About an hour and a half later, the sample was already saturated, as seen in Figure 5. Even though it was saturated, the samples were retained in water for about 4 days, so that the Waste could absorb more water, as observed by [15]. At the end of the days, the water retained in the Waste could drain freely. It is worth mentioning that a plastic film was placed over the samplers to avoid the loss of moisture to the environment.

Upon completion of the drainage period, the sample is taken to the greenhouse to obtain moisture in the field capacity.

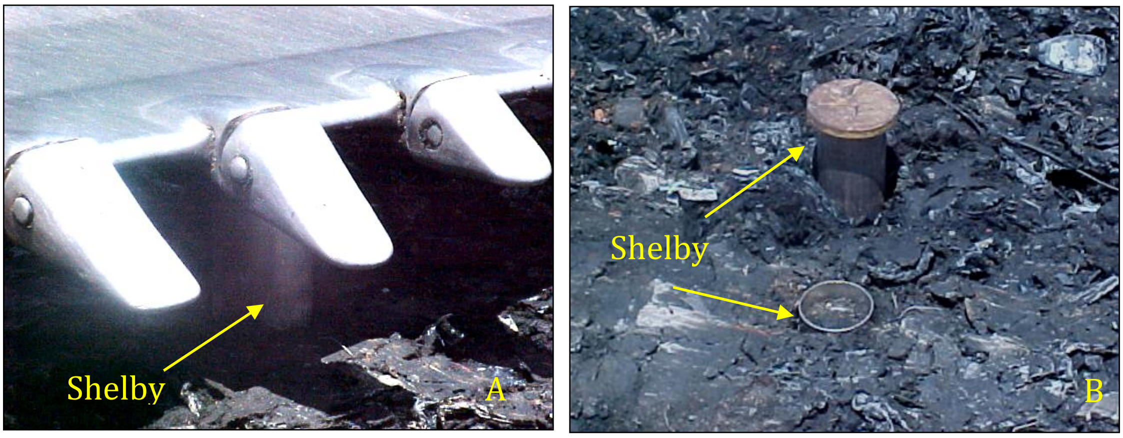

Figure 4: Preparations and subsequent driving. (A) Regularization of the mass of Waste. (B) Spiked Shelby.

Figure 5: Procedures in the laboratory (A) Sample saturation by the process of communicating vessels (B) Free Drainage of the Waste sample.

One of the restrictions of this type of field capacity test is the loss of moisture in a natural way through evaporation, as well as it is not carried out at great depths in the soil for making the collection of samples without great deformations.

3. Results and Discussion

In this stage, analyzes referring to soil and waste variables obtained in the Aterro da Muribeca will be presented, in addition to obtaining the field capacity of the covering soil and the waste.

3.1. Soil Field Capacity

Through the setting of 10 (ten) Shelby on the Waste cover layer, it was possible to obtain the soil granulometry that is causally related to the texture. After the field capacity test in all samples, the granulometric test was carried out, which indicated two clayey sands, another three silty clays and five other silts. As the silty soil is predominant, the analyzes and correlations of the field capacity were all focused on this type of soil, disregarding the other samples, since several authors [16,17] affirm that it should not be studied, simultaneously, soils of different textures and correlate them with field capacity. Through analyzes based on silty soil, a relationship is noticed between the percentage of fines (Clay + Silt) present in the soil and the field capacity. According to Figure 6, of the Soil Field Capacity versus Fines Content, it is observed that the Soil Field Capacity is directly related to the Fines Content contained in the soil, this statement being in agreement with [16] , where the results show the close dependence of moisture on the Field Capacity in relation to the soil texture. The “r” correlation reached 90%. According to Figure 7, from the graph relative to the values obtained for the Field Capacity of a silty soil, the values of the field capacity, volumetric, are observed, varying from 30 to 39% where, on average, the value was 35 %. For Field Capacity, in gravimetric value, the average was 23%. [18] in his master's thesis he obtained the volumetric humidity in the field capacity, for the fine clay sand, the value of 24.95%. Reference [19] in the Agronomy area, obtained for voluminous soils around 23.8% the volumetric humidity in the field capacity.

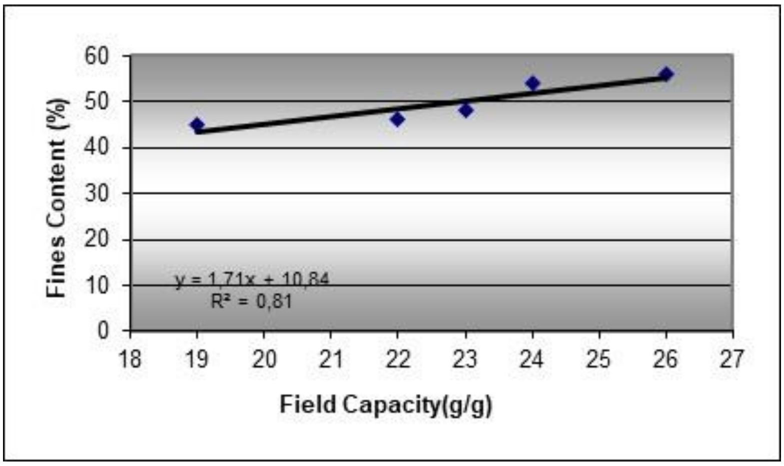

Figure 6: Soil Field Capacity *versus* Fine Content for the Aterro da Muribeca**.**

The soil structure can be changed through compaction, where it is related to the structure. As the soil is a porous material, by compression, the same mass of solid material can occupy a smaller volume, affecting the structure, the arrangement of the pores, the volume of pores and the water holding power of the soil. According to Figure 8, in the graph of dry specific weight versus field capacity of the soil, a reduction in field capacity is observed with the gradual increase of the specific gravity of the soil. This is due to the reduction of pores and, consequently, the reduction of the water holding power by the soil, directly influencing the field capacity. The r correlation reached 89.4%.

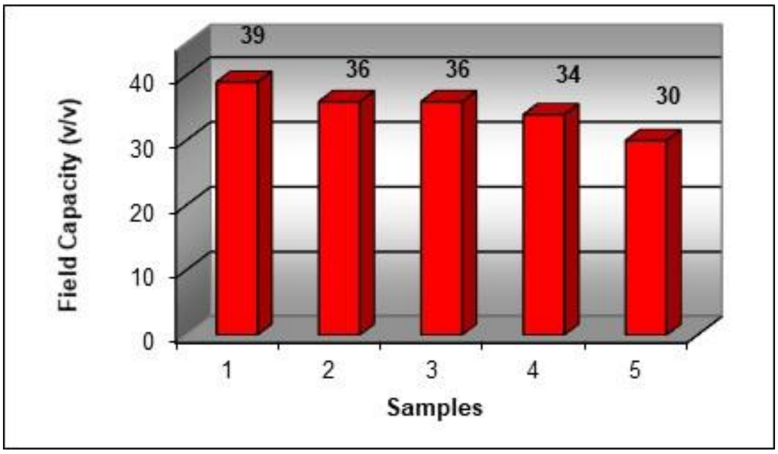

Figure 7: Graph relative to the values obtained from the Field Capacity for Silty Soil.

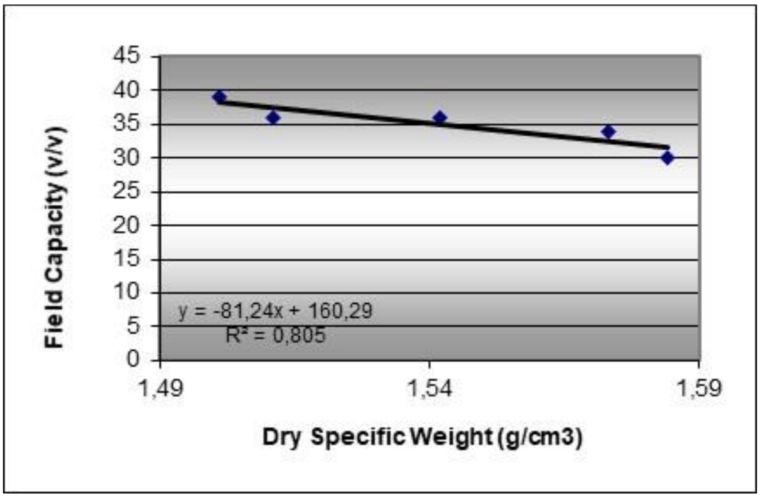

Figure 8: Dry Specific Weight versus Soil Field Capacity graph for the Aterro da Muribeca.

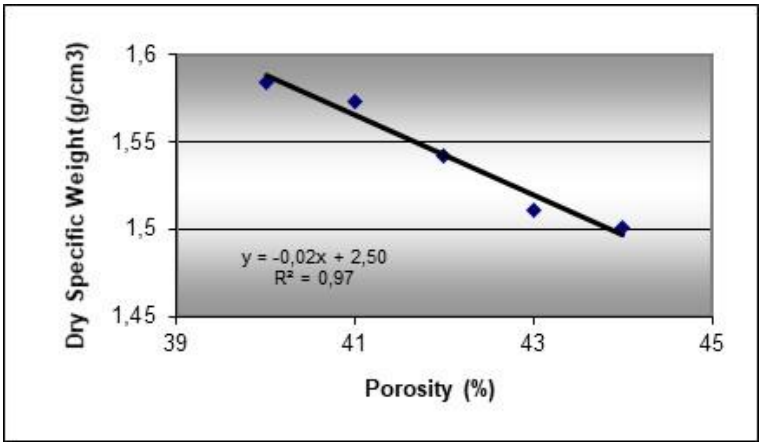

Figure 9: Graph of Total Porosity versus Soil Field Capacity for the Aterro da Muribeca.

According to Figure 9, of the graph of porosity versus field capacity of the soil, there is an increase in field capacity with porosity. If porosity is the relationship between the void volume and the total volume, the greater the void volume of a given mass, the greater its retention capacity, with a similar reasoning for the void index, as shown in Figure 10, a Since the void index is the ratio of the void volume to the volume of the solid particles. For the graph of total porosity versus field capacity of the soil, a r correlation of 94.3% was obtained and for the graph of the voids index versus field capacity of the soil, a r correlation of 89.4% was obtained.

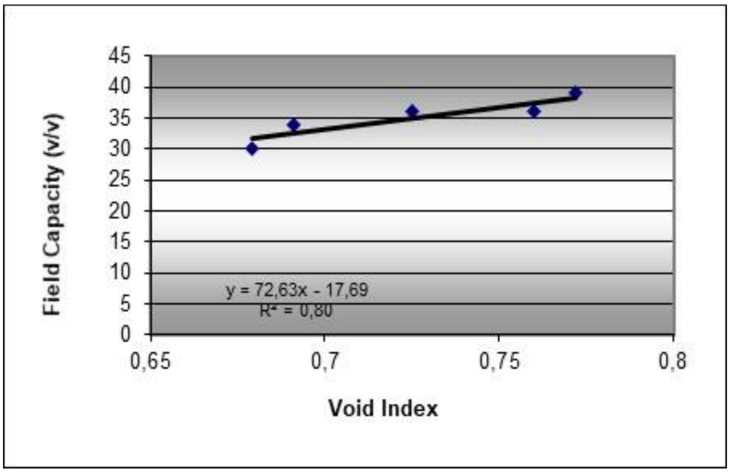

Figure 10: Void Index versus Soil Field Capacity.

In Figure 11, of the graph relative to the approximate values obtained for the Field Capacity of the Soil and the Degree of Saturation of the samples, it is observed that the samples are not saturated when they reach the field capacity, being in accordance with the definitions of field capacity that indicate that the soil after drainage is unsaturated, with only the micropores full of water. As observed in previous tests and analyzes, the field capacity, on average, for the covering soil of Aterro da Muribeca, was 35%. Using the characteristic curve, a suction of 11 KPa is obtained, worth noting that the humidity of the field capacity is not equal to the saturation humidity. This means that a suction equal to or greater than 11 KPa would be necessary, considering a uniform field capacity for the landfill, to remove the water retained in the field capacity condition. According to [20], they observed that, in 71 soils, the moisture equivalent correlated with the balanced water content in the malt potential of 33 kPa. Reference [21] established the value of 3.44 m, (30 kPa, 1/3 atm), the most used today. According to [22], the water content in the 33 kPa matrix potential for temperate regions correlates well with the field capacity due to the presence of high activity clay. Reference [23] state that soils with a clay texture also have a good correlation with this potential. For a suction of 33 KPa, a volumetric humidity of 30% is obtained in Figure 12.

Several authors have postulated that the field capacity for tropical soils would correspond to stresses ranging from 6 to 10 kPa [24,25,26]. The adoption of a certain voltage representative of the field capacity is of general interest, given the practicality of quickly characterizing its corresponding humidity, through characteristic water retention curves. According to [27] from works carried out for soils in temperate regions, with different physical-hydric and morphological characteristics from those of tropical regions, the water content corresponding to the malt potential of 33 kPa was adopted as representative of the capacity field, since there is a facility to obtain it in the laboratory.

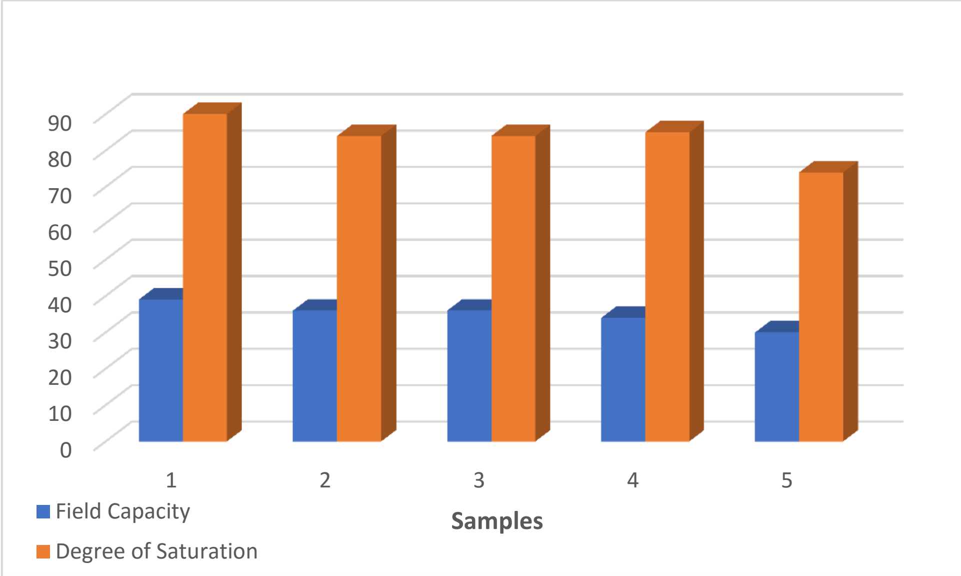

Figure 11: Graph relative to the approximate values obtained for the Soil Field Capacity and the Degree of Saturation of the samples.

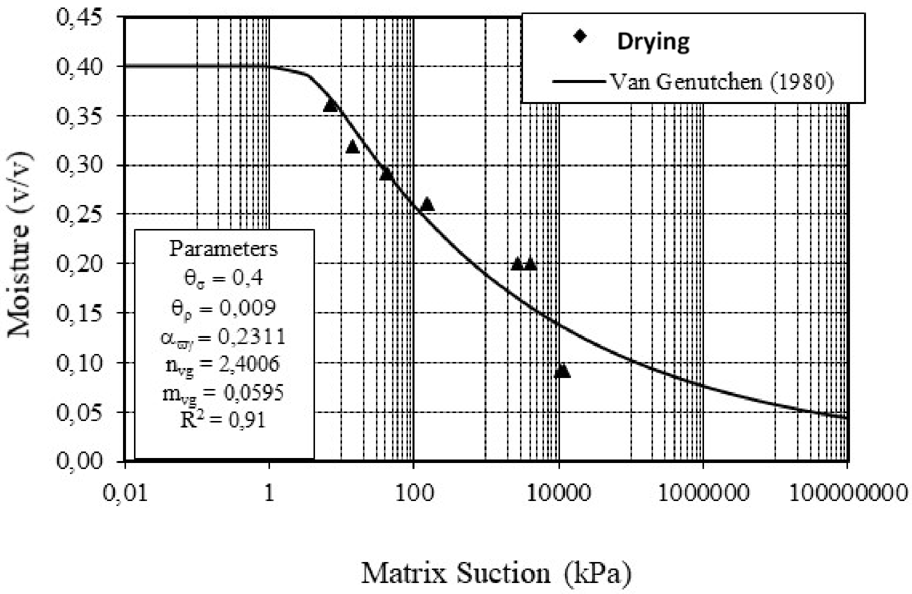

Figure 12: Characteristic curve of the ground cover of Aterro da Muribeca.

3.2. Waste Field Capacity

3.2.1. Age 5 Years (New Waste)

Through the setting of 6 (six) small Shelby in the superficial and level layer of the Waste, it was possible to obtain samples for the field capacity tests of the new Waste, as already explained. The waste considered new was aged up to 5 (five) years, and samples were taken to a depth of 40 cm. According to Figure 13, of the Graph relative to the values obtained for the Field Capacity of New Waste, the values of field capacity, volumetric, are observed, varying from 43 to 56% where, on average, the value was 50 %. These values are compatible with [28,29], which claim to have a field capacity for new waste of around 80%. Reference [30] observed values of volumetric field capacity ranging from 29.4 to 59.4%, and with values compatible with [31] where the volumetric field capacity varied from 32 to 56%. For this research, the Field Capacity, in gravimetric value, the average was 44%. In Figure 14, of the graph relative to the approximate values obtained for the Field Capacity of the New Waste and the Degree of Saturation of the samples, it was observed that the samples are not saturated when they reach the field capacity.

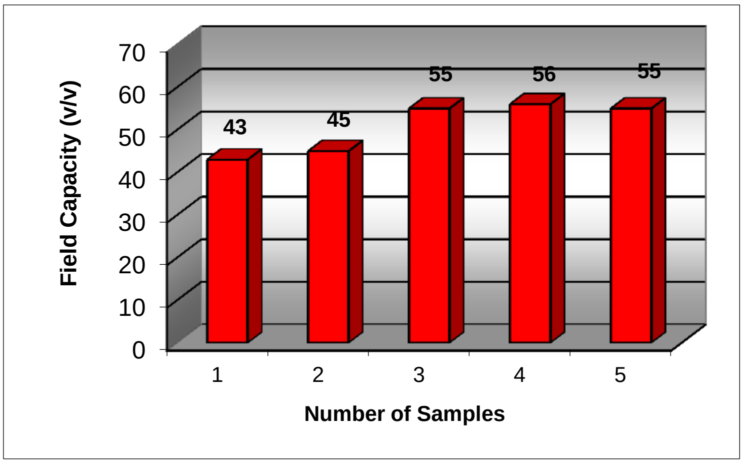

Figure 13: Graph concerning the values obtained for the Field Capacity of the New Waste for the Aterro da Muribeca.

According to Figure 15, of the Dry Specific Weight *versus* New Waste Field Capacity Graph, there is a reduction in the field capacity of the Waste with the gradual increase in the specific weight of the Waste. This is due to the reduction of macropores and, consequently, the reduction of the water holding capacity by the waste, directly influencing the field capacity of the waste. The "r" correlation reached 92.9%. This correlation confirms the claims of [32,33], which also proved a reduction in field capacity with an increase in density or compactness. In turn [34] found, through experimental results, an increase in field capacity values, expressed by volumetric humidity, with the specific weight of the residues. [35] also noted that field capacity increased with specific weight, both for new and old waste. The highest values were observed for new residues, that is, for those that are in a less advanced stage of decomposition and that therefore contain a large amount of organic matter.

According to Figure 16, the graph of total porosity versus field capacity of new waste shows an increase in the field capacity of waste with porosity. If porosity is the relationship between the volume of voids and the total volume, the greater the volume of voids, the greater will be their retention capacity, with a similar reasoning for the void index, as shown in Figure 17, of the graph of void index versus true. field capacity of new waste since this is the ratio of the volume of voids to the volume of solid particles. For these graphs, an "r" correlation of

92.7% and 92.8% was obtained, respectively.

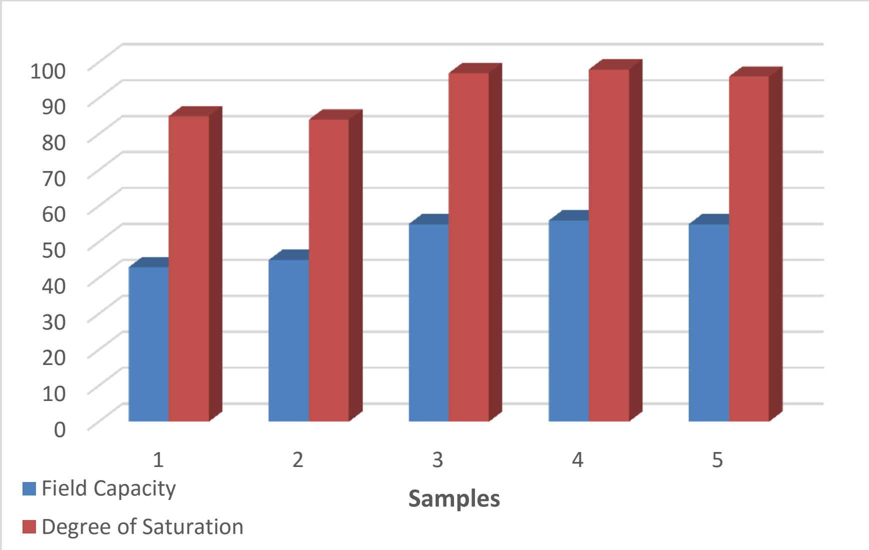

Figure 14: Graph relative to the approximate values obtained for the Field Capacity of the New Waste and the Degree of Saturation of the samples for the Aterro da Muribeca.

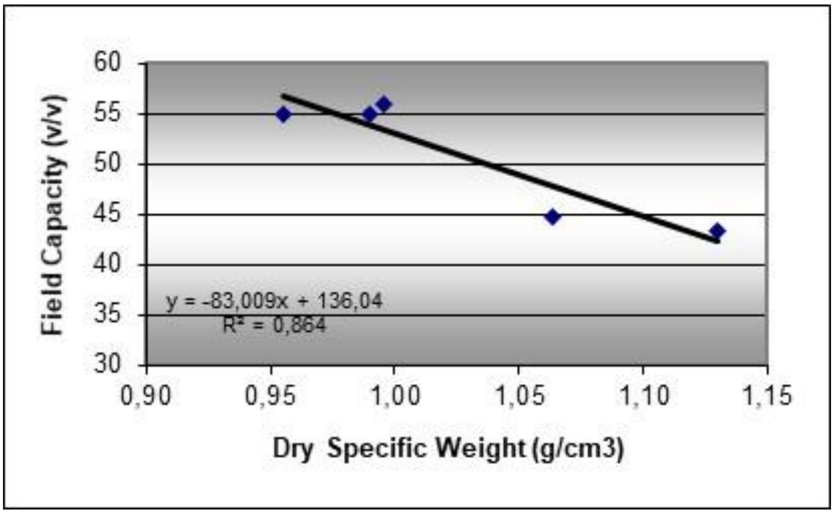

Figure 15: Dry Specific Weight versus Field Capacity of New Waste for the Aterro da Muribeca.

Reference [36] in his doctoral thesis, he carried out small analyzes regarding this correlation, where for the 1 simulation for a porosity equal to 0.671, he obtained a field capacity equal to 0.292 and a saturated hydraulic conductivity equal to 10^{-3} cm / s. In the second simulation, it obtained a porosity equal to 0.6, for a field capacity equal to 0.37 and a saturated hydraulic conductivity equal to 10^{-4} cm / s. From a general model, the author obtained important indications about the beneficial effect of compaction in the generation of percolated liquids.

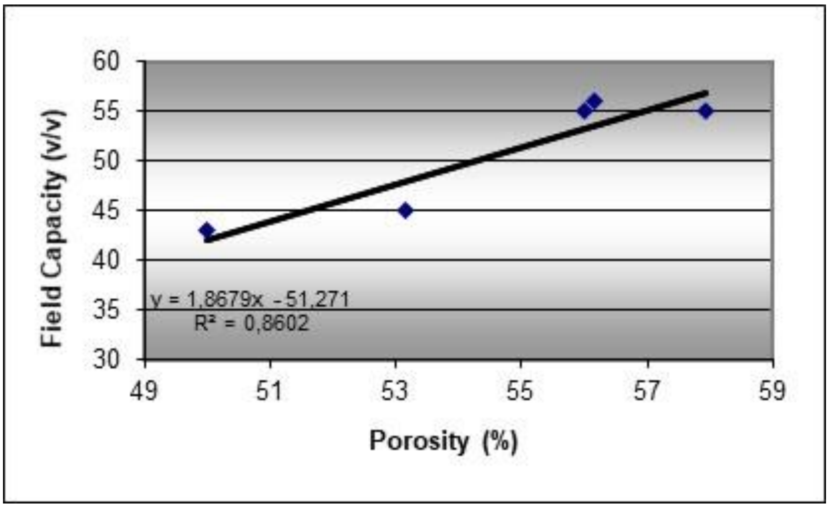

Figure 16: Total Porosity versus Field Capacity of the New Waste for the Aterro da Muribeca.

In a solid waste landfill, the field capacity of the waste changes rapidly during the first days of operation, due to the movement of vehicles over them and the placement of the cover layer. Reference [36] further states that this value decreases with the age of the waste, which can be justified by the mineralization of organic matter and the increase in the specific weight of the waste mass and the consequent reduction in porosity.

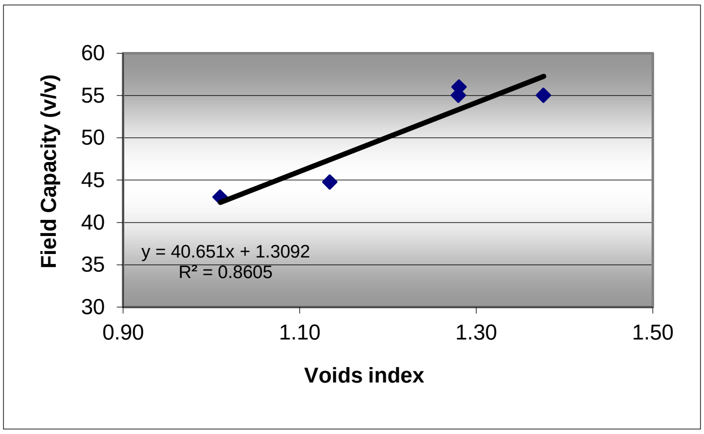

Figure 17: Void Index *versus* Field Capacity of New Waste for the Aterro da Muribeca.

According to Figure 18, of the Dry Specific Weight versus Total Porosity of the New Waste Graph, there is a close correlation (r = 99.8%) between the variables, where the porosity increases with the reduction of the dry specific weight of the waste. The average porosity for the Waste was 55% and its average dry specific weight was 1.03 g/cm^3. The waste field capacity is the content of moisture that the porosity of the material stores in your pores depending on your capillarity. It is the amount of water retained in the soil after the excess of water as opposed to the force of gravity has been drained and the rate of movement descending water decreases to become minimal. In practical terms, implies that if a minimum amount of water is added to the environment porous, in field capacity, an equal amount of water will drain so that moisture balance is restored.

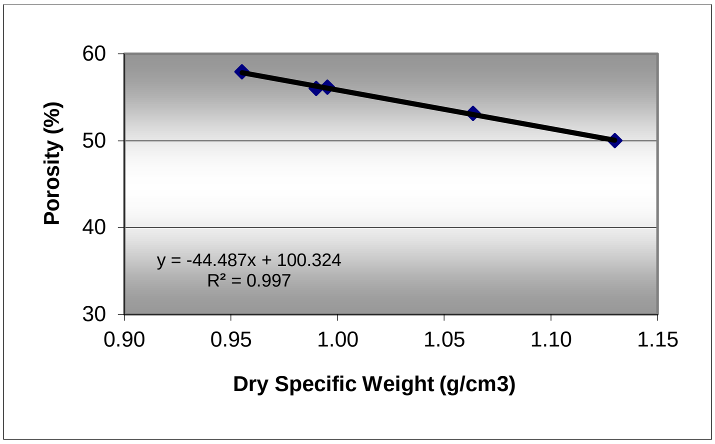

Figure 18: Dry Specific Weight versus Porosity of the New Waste for the Aterro da Muribeca.

3.2.2. Age 10 Years (Old Waste)

Through the same test methodology carried out for new waste, it was possible to obtain samples for the field capacity tests of old waste. The waste considered old was 10 (ten) years old, and six samples were taken to a depth of 40 cm. According to Figure 19, of the Graph relative to the values obtained for the Field Capacity of Old Waste, the values of the field capacity, volumetric, are observed, varying from 30 to 44% where, on average, the value was 38% . These values are compatible with [29,37] where both claims to have a field capacity for Waste between 29 to 42%, in addition to [38], which indicates a value of 44%. The value of Gravimetric Field Capacity, on average, was 29%. In Figure 20, on the graph of the approximate values obtained for the Field Capacity of the Old Waste and the Degree of Saturation of the samples, it is observed that the samples are not saturated when they reach the field capacity. Reference [39] demonstrated that field capacity has a variable behavior, without any observable characteristic behavior, with values ranging from 22.71 to 45.14% and an average value of 37.51%.

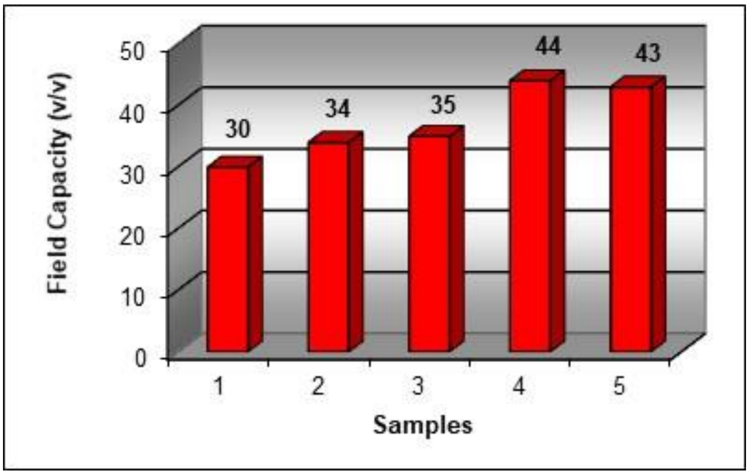

Figure 19: Graph relative to the values obtained for the Field Capacity of Old Waste for the Aterro da Muribeca.

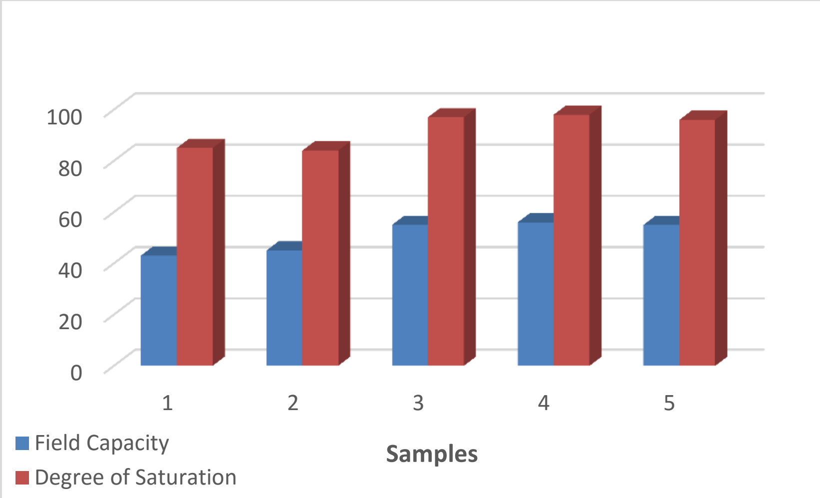

Figure 20: Graph relative to the approximate values obtained for the Field Capacity of the Old Waste and the Degree of Saturation of the samples for the Aterro da Muribeca.

According to Figure 21, of the Dry Specific Weight versus Field Capacity of the Old Waste Graph, a reduction in the field capacity of the Waste is observed with the gradual increase of its specific weight. This is due to the reduction of macropores and, consequently, the reduction of the water holding capacity by the waste, directly influencing the field capacity of the waste. The "r" correlation reached 98.9%. This correlation confirms, once again, the claims of [32,33]. According to Figure 22, of the Total Porosity versus Field Capacity of Old Waste chart, there is an increase in field capacity with porosity. If porosity is the relationship between the void volume and the total volume, the greater the void volume in a given mass, the greater its retention capacity, with a similar reasoning for the void index, as shown in Figure 23 of the Graph Void Index versus Old Waste Field Capacity. For the Total Porosity versus Field Capacity of the Old Waste Chart, a 99.5% "r" correlation was obtained and for the Void Index versus Field Capacity of the Old Waste, a "r" correlation of 98 was obtained, 5%. Reference [35] in turn found an inverse relationship with field capacity values ranging from 9% to 20% for old waste.

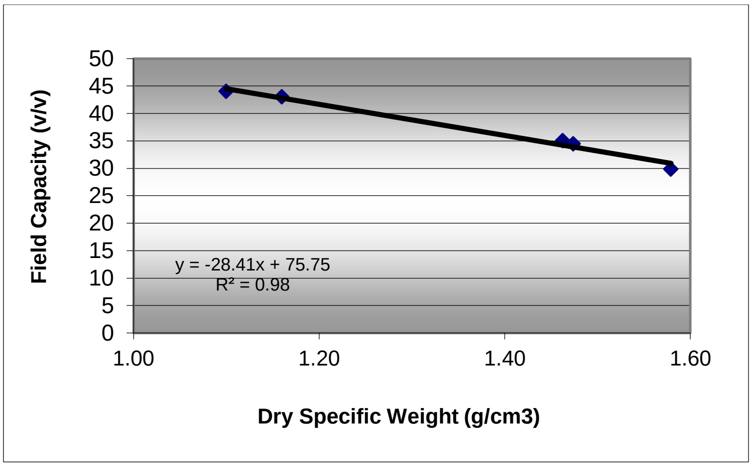

Figure 21: Dry Specific Weight *versus* Field Capacity of the Old Waste for the Aterro da Muribeca.

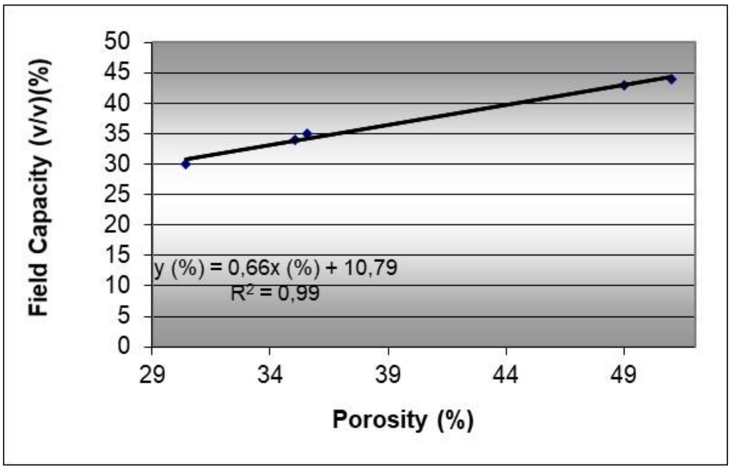

Figure 22: Total Porosity *versus* Field Capacity of the Old Waste for the Aterro da Muribeca.

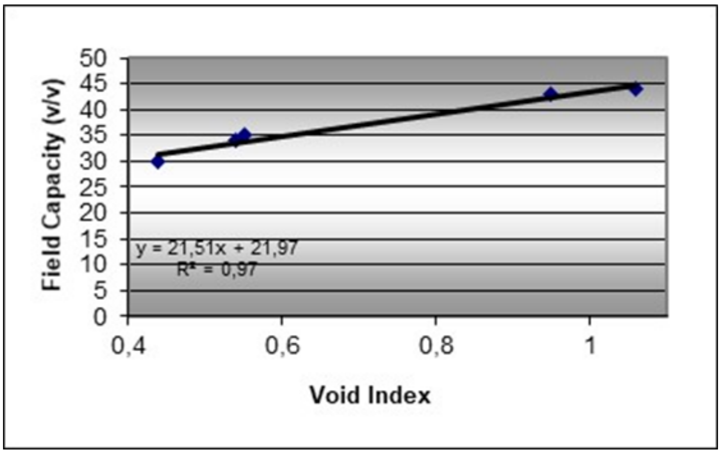

Figure 23: Void Index *versus* Field Capacity of Old Waste for Aterro da Muribeca.

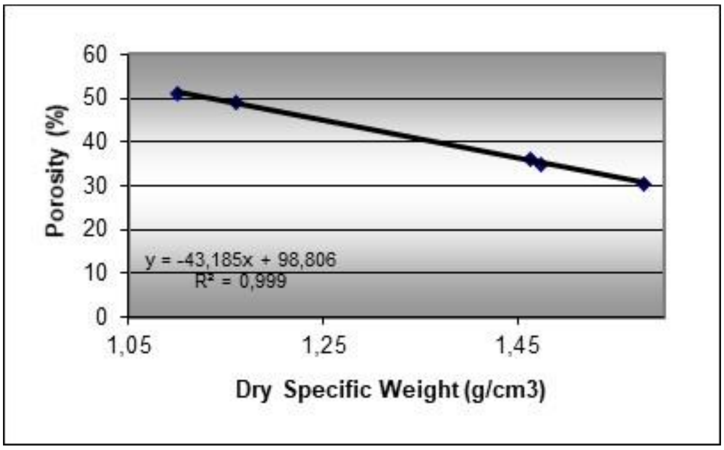

Figure 24: Dry Specific Weight *versus* Total Porosity of the Old Waste for the Aterro da Muribeca.

According to Figure 24, of the Dry Specific Weight versus Total Porosity of the Old Waste Graph, there is a close correlation (r = 100%) between the variables, where the porosity increases with the reduction of the dry specific weight of the Waste. The average porosity for the Waste was 40% and its average dry specific weight was 1.36 g / cm^3. [39] also found that there is a linear and inverse relationship between the behavior of specific weight and porosity. However, the author did not study the age of the residues.

4. Conclusion

- Soil Field Capacity is related to porosity and fines content, and inversely to density. Consequently, the higher the fines content and the porosity present in each soil type, the greater the matrix suction and the field capacity.

- Matrix Suction is another variable of paramount importance for a good understanding of the behavior of the field capacity of the soil. For Aterro da Muribeca, the covering layer of the Waste mass obtained was silt, its average field capacity was 35% and the equivalent matrix suction of 11 KPa for this time of year. The average total porosity for the soil covering the waste mass of Aterro da Muribeca was 42% and its average dry density was 1.54 g / cm^3.

- A soil, when reaching field capacity, is always unsaturated, and, consequently, with non-zero matrix suction. In this case, the macropores are empty (filled with air), and the micropores are saturated with water.

• There was a close correlation between Total Porosity and Fines Content (r = 96.4), where total porosity increases with the fines content in the soil, especially if this soil has a large clay content, a since most soils rich in clays (not excessively compact) have greater total porosity with a predominance of micro porosity.

- The average field capacity found for Waste aged 5 years was 50% and for Waste aged 10 years ago it was 38%. This lower field capacity for older waste can be justified by the mineralization of organic matter (which has great absorption power) and the increase in the specific weight of the waste mass and the consequent reduction in porosity.

- As well as the soil, the porosity and the composition of the waste are directly related to the water holding capacity, and, consequently, a greater field capacity. Conversely, the density is also related to the field capacity of the waste.

- Waste samples, in the field capacity condition, are not saturated.

- The average porosity obtained for Waste aged 5 years was 53% and its average dry density was 1.03 g / cm^3. For 10-year-old Waste, the average porosity obtained was 40% and its average dry specific weight was 1.36 g / cm^3. It is noteworthy that these values are certainly not the actual values of density and porosity, respectively, for the given mass of Waste, since through the setting of the samplers there will be an increase in these variables. What must be considered here is exactly the difference between the density and porosity of the masses of Waste for different ages.

- One of the restrictions of this type of field capacity test is the loss of moisture in a natural way through evaporation, as well as it is not carried out at great depths in the soil for making the collection of samples without great deformations.

5. Recommendations

Based on the research findings, it is recommended that:

- Study the field capacity at different depths, making a new correlation with density, porosity, void index, age of the waste, inserting a new variable, such as hydraulic conductivity. In addition, another point to be studied would be the influence of the waste composition on the field capacity.

- A period of collection, of humidity of soil and garbage, much greater than the one carried out for this dissertation is carried out.

- The infiltration calculation, for the Field Capacity Method, based on soil moisture and hydraulic conductivity.

- A study is carried out relating the variation of the field capacity with the settlement and the generation of biogas.

Acknowledgements

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