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Optimum soil moisture for urban solid waste disposal purposes

Umidade ótima do solo para fins de disposisção de resíduos sólidos urbanos

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Abstract: The generation of solid waste combined with the proper disposal of these wastes are determining factors in landfills both for the environmental issue and for public health. In this context, the physical variables of the soil in relation to the permeability of the soil are essential for the safe operation of landfills. Therefore, this study aims to determine the optimal soil moisture for maximum compaction. The study was carried out in the area of a sanitary landfill, located in northwestern Rio Grande do Sul. The local soil is a RED LATOSOL (Oxisol), in which the compaction test was carried out by the Proctor method and subsequent determination of the saturated hydraulic conductivity, by means of a constant load permeameter. The results indicated a clay percentage of 65 %, which resulted in an optimum moisture content of 34 %, maximum density of 1,395 $kg.m^{-3}$, saturated hydraulic conductivity of 2.1 x 10^{-6} $cm.s^{-1}$. Thus, it can be concluded that the clayey soil presented the minimum values proposed by the current legislation for the operation of urban waste landfills, in addition to serving as an aid in the decision-making process by management bodies.

Keywords: Landfill; Proctor assay; Permeability.

Resumo: A geração de resíduos sólidos aliado à disposição desses resíduos de maneira adequada são fatores determinantes em aterros sanitários tanto para a questão ambiental quanto para a saúde pública. Nesse contexto, as variáveis físicas do solo com relação a permeabilidade do solo são essenciais para a segurança da operação dos aterros. Diante disso, esse estudo tem por objetivo determinar a umidade ótima do solo para a sua máxima compactação. O estudo foi desenvolvido na área de um aterro sanitário, localizado no noroeste gaúcho. O solo local é um LATOSSOLO VERMELHO, no qual foi realizado o ensaio de compactação pelo método do Proctor e posterior determinação da condutividade hidráulica saturada, por meio do permeâmetro de carga constante. Os resultados indicaram uma porcentagem de argila de 65 %, o que resultou em um teor de umidade ótima de 34 %, densidade máxima de 1.395 $kg.m^{-3}$, condutividade hidráulica saturada de 2,1 x 10-6 $cm.s^{-1}$. Com isso, conclui-se que o solo argiloso, apresentou os valores mínimos propostos pela legislação vigente para operação de aterros sanitários de resíduos urbanos, além de servir como auxílio no processo de tomada de decisão por órgãos gestores.

Palavras-chave: Aterro sanitário; Ensaio proctor; Permeabilidade.

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1. Introduction

The Solid Urban Waste Management process (USW) involves a series of regulations and legislation on the subject. In this sense, landfills play a key role as a form of environmentally appropriate final disposal of tailings. However, when operated improperly, it becomes a potential source of contamination of the physical environment (soil and groundwater).

In this context, the physical environment, especially the soil, plays a key role in protecting the environment, because it ends up working as a filter (REBOUÇAS; BRAGA JÚNIOR; TUDISI, 2002). Otherwise, this contaminant load can infiltrate the aerated zone to the vadose zone, reaching the groundwater, where the impacts are aggravated, polluting the environment and affecting its quality.

Therefore, research that aims to analyze the support of the environment for the operation of landfills are extremely important. In this sense, determining the optimal moisture for maximum compaction in the laboratory becomes essential information for the operation of landfills, as it aims at a lower rate of infiltration at the base of the structure or even for the final coverage.

One of the most common methods of determining the optimum soil moisture is the Proctor test. This compaction test takes into account the compaction of the soil and its moisture content. Klein (2014) states that as the moisture content increases, the particles rearrange themselves into a more compact state, and after a certain water content, compaction can no longer expel air from the pores, thus generating the optimum humidity.

Given the relevance of the topic, several studies refer to the optimal humidity in landfill areas, either in base or final coverage layers (NIK DAUD; MUHAMED; KUNDRIRI, 2017; BECK-BROICHSITTER; GERKE, HORN, 2018; COSTA et al., 2018; SobreIRA et al., 2008; ARIFIN, 2019; BECK-BROICHSITTER, GERKE. HORN, 2019; EMMANUEL et al., 2020; DALA SANTA et al., 2020). Based on the above, this study aims to determine the optimal soil moisture for MSW disposal in an area located in the northwest of the State of Rio Grande do Sul. permeability of samples.

2. Metodology

To determine this study, soil samples were collected in the area of the Intermunicipal Solid Waste Management Consortium (CIGRES), located on the margins of BR 386/158, located in the municipality of Seberi - RS (Figure 1).

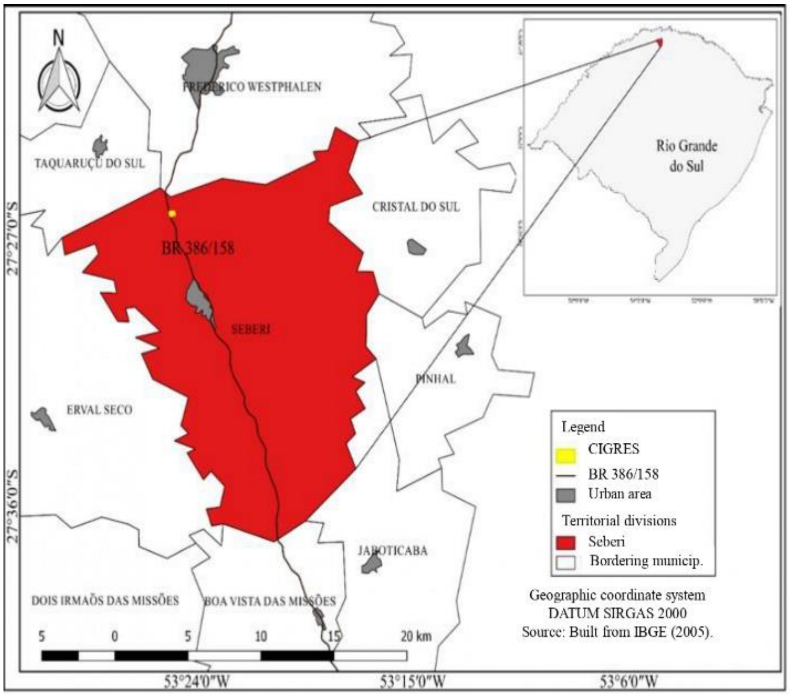

Figure 1 – Location of the study area.
Source: Borba (2019).

CIGRES is located in the hydrographic region of the Uruguay River (U), Várzea River Basin - U100 (SEMA, 2004), with a humid subtropical climate (MORENO, 1961) and contemplates a total annual rainfall close to 1900 mm, diffused in the 12 months of the year (SOTÉRIO; PEDROLLO; ANDRIOTTI, 2005).

Currently, CIGRES receives about 1,700 tons of MSW per month, coming from 31 municipalities that send waste from a population of approximately 160,000 inhabitants. In addition, it carries out the process of screening, destination and environmentally adequate disposal. The sorting process manages to recover about 16 % of the amount received (BORBA, 2019) and 84 % is disposed of in the landfill. In addition to the information of interest, studies carried out by Borba (2016; 2019) were used as a database, when necessary.

2.1. Soil collection, particle size analysis and particle density

The local soil is a dystrophic RED LATOSOL (EMBRAPA, 2017), Oxisol in Soil Taxonomy, originating from the Serra Geral Geological Formation (CPRM, 2006) and its weathering products. Soil collection to determine the parameters of interest was carried out in a place where the tailings disposal cell will be implemented.

Thus, a trench was built (Figure 2), where the deformed samples were collected at a depth between 2 and 2.5 m. This is due to the fact that for the implementation of the cell, the cell base will be close to these values, due to excavation and levelling. To determine the soil granulometry was used the pipette method (EMBRAPA, 2017).

Figure 2 – Location of the analyzed soil collection point.
Source: Author (2019).

The particuly density was determined by ballon volumetric method, following what was proposed by Viana, Teixeira and Donagemma (2017), according to equation 1.

$$Dp = ma/((Vt-Va)) \qquad \text{Equation 1.}$$

Where:

- Dp: Particle density, in $g.cm^{-3}$;
- ma: Mass of the sample dried at 105 ºC, in g;
- Vt: total volume measured of the balloon, in mL; and
- Va: Volume used to complete the flask with the sample, in mL.

2.2. Soil compaction test (PROCTOR)

For the Proctor test, 3 kg of soil was separated, sieved in a 4.75 mm sieve and stored in closed plastic bags, as proposed by NBR 7.182/2016 (ABNT, 2016). As a compaction base, the material was reused and a small cylinder was used, and a base socket for the same cylinder. Where there is a 1,000 cm³ cylinder and a socket weighing 2.5 kg, with a drop height of 30.5 cm, using three layers of soil compacted by 26 blows per layer (ABNT, 2016).

In order to determine the compaction curve, the sample was initially moistened to get close to a known value of moisture, that is, to start the test, 20 % of water was added in relation to the sample's dry soil. Afterwards, water was added increasingly, where, between repetitions, 2 % was added until reaching a time when the maximum density found resulted in a lower value than the previous one, to thus end the tests, always making a homogeneous mixture for a better application of the methodology.

As shown in Figure 3, each moisture produced was placed in the cylinder in layers, in a total of 3 layers for a better homogenization of compaction, with 26 strokes applied to each.

Figure 3 – Soil compaction using Proctor.
Source: Author (2019).

Each time a new sample was generated, with a new moisture, two models were collected in smaller cylinders (Figure 4), to be placed in an oven and to check the known actual moisture, to prove the moisture content used in each compaction model. Afterwards, an electronic spreadsheet was carried out to calculate the specific maximum apparent dryness and optimum moisture content.

Figure 4 – Cylinder with compacted soil to collect density data.
Source: Author (2019).

2.3. Saturated hydraulic conductivity

The determination of samples to calculate the Saturated Hydraulic Conductivity (ksat) was based on the knowledge of the optimum moisture content and the maximum apparent density of dry soil. For this, the material was placed in a cylinder of 100 cm³, through manual compaction. At this stage, samples were collected in triplicate.

Afterwards, the samples were saturated for a period of 24 hours. The ksat was performed using a constant charge permeameter, as described by Marques et al. (2008). A constant hydraulic load of 8 cm cylinder area of 19.63 cm² was used. The saturated hydraulic conductivity was obtained from equation 2.

$$Ksat = ((Q.L)/(A.H.t)) \qquad \text{Equation 2}$$

Where:
- ksat: saturated hydraulic conductivity ($cm.s^{-1}$);
- Q: Pearl volume (mL);
- L: Height of the soil block (cm);
- H: Height of water column and block (cm);
- A: Cylinder area (cm²); and
- t: Percolation time (s).

Time and volume were collected at two-hour intervals, in order to have homogeneity of results, the measurement of time was measured by a stopwatch and the percolated volume was measured with a pipette.

3. Results and discution

The soil granulometry showed average values of 66% clay, 25 % silt and 9 % total sand. According to Chernicharo et al. (2008), the areas of sanitary landfills must contain a percentage of clay above 30 % to meet the permeability needs and the presence of clay minerals that act as a filtering element for contaminants from the waste stored in these places. Studies carried out in landfill areas by Silva et al. (2001), Beutler et al. (2005) and Fonseca et al. (2007), reiterate that average clay values must be between 43 and 62 %. In the study area, the predominance of clay is a very essential point, due to its low permeability characteristics.

Soil compaction is the reduction of the porous volume of the soil by mechanical effort on the soil surface. For the soil to be compacted, the soil moisture content is essential, water facilitates the movement and rearrangement of solid particles (SILVA; REINERT; REICHERT, 2000). The optimum moisture content obtained in the proctor test for this soil was 34% (Figure 5) to achieve maximum compaction. This represents that the soil needed 34% of its dry weight to obtain the highest specific dry mass, thus, a lower void index in the soil, and consequently the lower permeability of the sample.

To obtain an optimal moisture content of 34 %, the maximum density was approximately 1,395 kg.m^{-3} or 1,395 kg.dm^{-3}. Pinto (2006) states that clayey soils, such as the Latosol present in the study area, have optimum moisture content between 25 and 30 % and maximum dry densities of 1.4 to 1.51 kg.dm^{-3}, values that are close to those found in the analyzed area.

For Maciel (2003), in a soil with 27 % clay and 24 % silt, the maximum dry density of the soil was 1,610 kg.m-3, for a moisture content of 23 %. Thus, we can analyze that the higher the percentage of clay, the higher the moisture value needed for compaction, as for a clayey-silty soil (Soils < 40 % clay), Carvalho and Paschoalin Filho (2004) obtained a moisture value optimal at 28 %. Ozcoban et al. (2006) describe that the percolation of leachate through the soil can change its permeability, increasing its values. Thus, the importance of protecting the underground environment in these areas is highlighted.

In the study developed by Franceschet (2006) on soils from three landfills, the values found by the author for optimal moisture ranged from 23.60 to 36 %, for maximum density from 1.29 to 1.35 kg.dm^{-3} e for permeability, from 10^{-7} to 10^{-5} cm.s^{-1}. For the optimum moisture content of 32 %, the maximum density values were 1.35 kg.dm^{-3} and permeability of 10-5 cm.s^{-1}, values similar to those found in this study. Araújo et al. (2016) found, in a soil with optimum moisture content of 13.40 %, maximum density values of 1.99 kg.dm^{-3} and permeability in the range of 10^{-8} cm.s^{-1}.

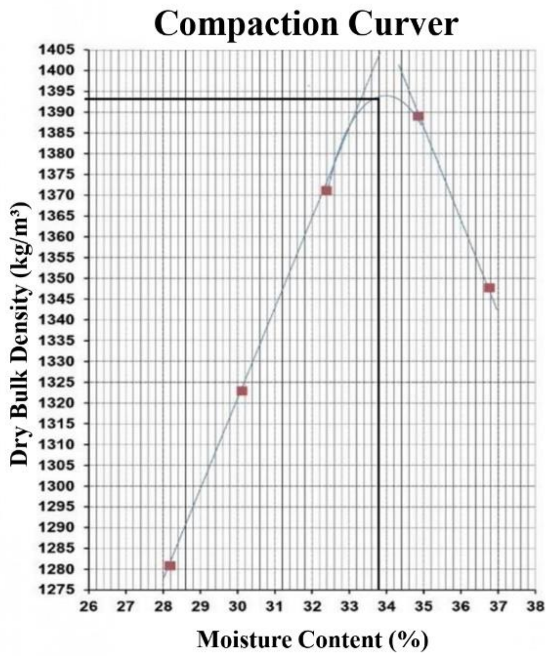

Figure 5 – Soil compaction curve in relation to soil moisture content.
Source: Author (2019).

The ksat conductivities of the soil were 2.1 x 10^{-6} cm.s^{-1}, values below those verified by Borba (2016; 2019) under natural soil conditions in that same location. The author found mean values of 1.20 x 10^{-4} cm.s^{-1} and 5.09 x 10^{-4} cm.s^{-1}, respectively. Thus, it is clear that the ex situ localized test presented lower values of saturated hydraulic conductivity, being within the limits allowed by landfills, NBR 13.896/1997 (ABNT, 1997) and NBR 15.849/2010 (ABNT, 2010), they indicate that the values should be less than 5 x 10^{-5} cm.s^{-1}.

Thus, the importance of knowing the optimum soil moisture is highlighted, in order to carry out soil compaction operations to achieve maximum site compaction, increasing safety for operation and consequent protection of the underground environment from percolation of water and contaminants . At the beginning of the water flow, the soil is not saturated and the movement of water and contaminants occurs in unsaturated conditions, involving characteristics of the soil, the solute and is affected by hysteresis (REICHARDT; TIMM, 2004). With the increase in the flow of water and contaminants, the water movement is defined as a flow in saturated soil, where the permeability conditions of the medium and the pressure potential difference at the considered point interfere in the movement.

In other studies involving soil permeability tests, Celligoi et al. (2006) in Londrina - PR, the soil from volcanic rocks presented values of 1.9 x 10^{-2} cm.s^{-1}. Pinheiro, Nummer and Rauber (2017) in Santa Maria - RS, obtained 3.3 x 10^{-5} cm^{-1}, for a soil with 65 % clay, a value similar to that found by Borba (2019). Furthermore, the local soil has liquidity limits of 68.39 %, plasticity of 41.73 %, contraction of 28.94 % and plasticity index of 27.10 % (Borba, 2016). According to Borba (2016), these values are in agreement with values described in similar soils, mainly due to the clay content of the same, in addition to the activity of this fraction.

Even so, information about the mineralogy of the sites is essential information, as it allows identifying which clay minerals are present. The mineralogy of the clay fraction in the area is predominantly kaolinite (Borba, 2016), a 1:1 silicate clay mineral, which has low Cation Exchange Capacity (CTC), being a common feature in weathered soils.

According to Drever (1997), these patterns can be related to the retention of heavy metals and provide a low permeability of the medium, as seen in the results obtained, through the ksat. The study developed by Piarangeli et al. (2007) and an Oxisol with low CTC, there was greater adsorption of the elements Copper and Lead, when compared to Cadmium. This indicates a possible retention of contaminants, even with the presence of a 1:1 clay mineral.

4. Final considerations

It is concluded with this study, that the sampled soil had an average clay content of 65 %, conditioned the soil with an optimal moisture content for maximum compaction of 34 % and maximum density of 1,395 kg.m^{-3}, which resulted at a saturated hydraulic conductivity of 2.1 x 10^{-6} cm.s^{-1}. Allied to this, the presence of kaolinite at the site contributes to low soil permeability values, and consequently, greater protection of groundwater.

The results allowed us to identify that the laboratory tests provided extremely important information, as compared to other studies carried out at the site, the optimal humidity resulted in a permeability value that is in accordance with current standards.

In landfill areas, studies of this thematic nature are extremely important, as they allow, in addition to providing maximum soil compaction, to assist in planning and reduce operating costs, for example, aiding in the decision-making process.

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