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Analysis of Geomechanical Parameters of a Non-Typical Sandy Soil

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Abstract

Municipal solid waste (MSW) landfill must have the stability of its slopes ensured. In this sense, it is necessary to investigate the stability of MSW landfills' slopes in different scenarios. Therefore, in this paper, shear strength of a soil from a landfill cover layer, which was compacted with different moistures, was evaluated to obtain the needed parameters for numerical analysis. The methodology applied was experimental and numerical. Experimental tests comprise particle size analysis, compaction to determine optimal water content, compaction in optimal water content ±4 %, and direct shear tests with the compacted samples. Numerical analyses were performed once soil parameters for each direct shear test scenario were obtained. These analyses were developed by a software applying the limit equilibrium method improved by Morgenstern & Price aiming to evaluate the geomechanical behavior of the landfill slopes concerning different soil moistures. It was observed that the soil presented similar cohesion and factor of safety (FS) evolution for the different moistures. In contrast, friction angle and soil friction reduced as the water content increased. In conclusion, it was observed that the soil presented a higher shear strength when it was compacted at the optimal water content.

Keywords: Environmental geotechnics; Slope stability, Shear strength; Numerical modeling.

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1. Introduction

The study of the mechanics of unsaturated soils has gained increasing prominence in Geotechnics since a large part of the Earth's surface presents partially unsaturated soils, with highlights for areas where there is no projection for saturation [1]. The condition of soil's non-saturation by water is observed in several situations for example in natural slopes and in municipal solid waste (MSW) landfill cover layer. In this context, the landfill cover layer must function as a barrier for waterproofing the waste to prevent precipitated water infiltration and, at the same time, the release of gases into the atmosphere [2]. Thus, to attend such requirements, the landfill cover layer must necessarily be composed of unsaturated soil. In addition to characteristics related to water and gases flow, the landfill cover layer, along with the waste mass disposed in the MSW landfill, shall have geomechanical properties in order to ensure the stability of the landfill slopes. A series of landfill accidents, which are related to the instability of slopes, have been reported. Among these accidents it highlights the Payatas Landfill accident, in Filipinas, when slopes failure causing the death of more than 300 people [3]; the Bandung Landfill accident, in Indonesia, in 2005, when hundreds of people were killed [4]; and in Brazil, accidents at Bandeirantes Landfill and Sítio São João Landfill, which handled between 65,000 and 220,000 tons of waste respectively [5]. In this sense, it is necessary to investigate the stability of MSW landfills slopes in different scenarios, which differ from each other compared to the different soil water content. In this paper, it was studied a soil from the landfill cover layer of the municipality of Altinho - Brazil, which comes from the same region where Belfort and his colleagues [6] collected soil for geomechanical studies. This soil studied by Belfort and his colleagues was classified as sandy. Besides, by field test to determine water permeability, the authors obtained as a result a value equals to 10^{-10} m/s, which is about 10,000 times lower than the permeability of some clays with typical behavior for water flow (10^{-6} m/s). Thus, the authors found that the soil presented an anomalous behavior related to water flow. Therefore, in this paper shear strength of a soil compacted with different water contents was evaluated in order to obtain the needed parameters for the numerical analysis of slope stability. In addition, it was projected to assess the influence of soil moisture on its shear strength. In order to verify the studied soil's geomechanical behavior, numerical modeling was performed applying the GeoSlope software. This software is based on the limit equilibrium method, which has several methodologies, such as the methods of Bishop Modified, Spencer, Fellenius [7], among others. Limit Equilibrium analyses have been widely applied in geotechnical engineering to verify the slope stability [8-10]. The method of [11] is one of stability analysis methods by limit equilibrium used to determine the minimum critical factor of safety. It consists on a method in which all equilibrium and boundary conditions are satisfied, and the failure surface can assume any form. Moreover, the method is one of the most rigorous when compared to other limit equilibrium models, such as Fellenius, Bishop, and others [12]. In this sense, several authors have used this method for slope stability analysis. Guo and his colleagues [13] proposed a rigorous analytical solution based on the principle of potential energy minimization in view of the need to preset the direction of global sliding in the use of Vector-Sum-Method. In order to verify the feasibility of the method, the authors compared the results found by the rigorous method Morgenstern & Price. Reference [14] used the Upper Bound Limit Analysis in conjunction with a discretization procedure, which is known as Discontinuity Layout Optimization, and compared it with the use of limit equilibrium methods by the Morgenstern & Price method to illustrate agreement between the analyses. Dong-ping and his colleagues [15] established a limit equilibrium analysis for the stability of a slope reinforced with a wire-anchored grid beam and, for such, made use of the Morgenstern & Price method. In view of this, it is observed that this method is nowadays used in geotechnical engineering [13-16] highlighting its use for validation of new proposed models; thus, it ensures its high accuracy, efficiency and robustness. Therefore, the calculation method of [11] was adopted for the development of this study. It is noticed that the limit equilibrium methods have limitations such as performing a static analysis with assumption of uniformly distributed stresses [8].

2. Materials and Methods

The methodology applied in this study was experimental and numerical. The experimental tests comprise particle size analysis, compaction to determine the optimal water content, compaction in optimal water content ±4 %, and direct shear tests with the respective compacted samples. Numerical analyses were performed once the soil parameters for each direct shear test scenario were obtained. These analyses were developed applying GeoSlope software to evaluate the geomechanical behavior of the landfill slopes concerning different soil moistures.

2.1. Experimental methodology

Firstly, the methodology consisted in performing grain size characterization test according to procedures described in NBR 7181 [17]. To execute the grain size characterization, it was needed to perform both sedimentation of the finer and sieving of the coarse materials to obtain the respective grain size, as well as the percentages of occurrence. Secondly, soil compaction was accomplished according to NBR 7182 [18] with the scope of obtaining the optimum water content. Once that parameter was obtained, soil compaction tests were carried out with water contents higher and lower than the optimum one in 4 %. It is worth mentioning that all compaction tests were performed in consonance with the standard Proctor compaction test using a 2.5 kg hammer with distance of the fall equals to 30.5 cm, three compacted layers, and 26 blows per layer. Aiming to determine soil strength parameters such as cohesion and internal friction angle, direct shear test under natural conditions was chosen. The procedures which were taken are standardized in ASTM D3080 [19]. It is worthy highlighting that the test pieces were all cubic with 5.0 cm of side; they were molded from compacted samples with moistures corresponding to the optimal water content and optimal water content ±4 %. The axial loads applied during the test were 100, 200, and 300 kPa. Tests were realized in the Soil Mechanics Laboratory at Federal University of Pernambuco (UFPE). Later, with the results obtained, the effective friction angle and cohesion were analysed for the three conditions (optimal water content and ±4 %). Hence, the change in shear strength and in the soil parameters with the increase of water content was evaluated.

2.2. Numerical analysis

Based on the experimental results presented at section 3.1, it was performed the slope stability analysis of a cell related to the MSW landfill located in Altinho, whose geometry is described in Figure 1. Besides, in Figures 1, 6, 7, and 8 the yellow part represents the landfill cover layer, and the green one represents the MSW mass.

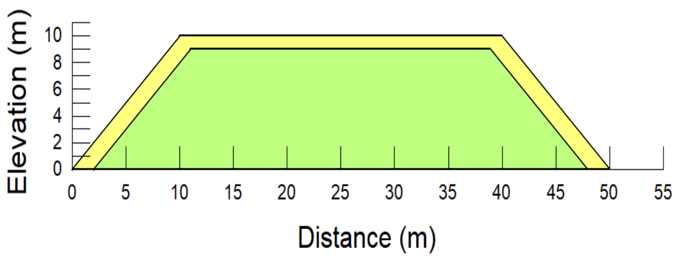

Figure 1: Cell geometry of MSW landfill located in Altinho -Brazil.

For this, solid waste physical parameters were obtained from the literature according to Brandão and his colleagues [20], and the parameters of the cover layer were based on the results of direct shear tests performed in the laboratory. The influence of moisture on soil resistance was then evaluated using the factor of safety (FS) based on soil parameters from its compaction optimum water content and ± 4 %. Thus, the slope stability analysis for the soil was performed in three scenarios, whose parameters are described in Table 2, section 3.1.

3. Results

3.1. Experimental results

According to the grain size characterization tests and the Unified Soil Classification System (SUCS), the soil tested was classified as clayey sand (SC), with 69% of sand. Figure 2 shows the grain size distribution curve and Table 1 presents the soil granulometric composition:

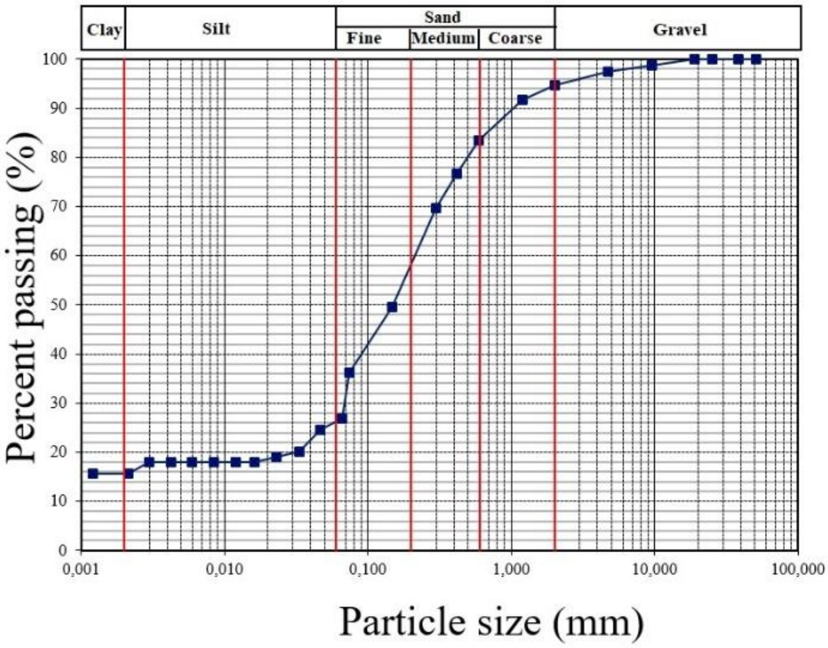

Figure 2: Grain size distribution curve

Table 1: Soil granulometric composition

Gravel (%)	Coarse Sand (%)	Medium Sand (%)	Fine Sand (%)	Silt (%)	Clay (%)
5	11	26	32	10	16

By compaction test it was found that maximum dry unit weight of the sample is 19.16 kN/m^3 and the respective optimal water content and void ratio are respectively 12% and 0.38. Then, the other samples were compacted with water contents equal to 8 and 16%. Figures 3, 4, and 5 show the direct shear curves of the sampled soil compacted with water contents equal to 8, 12, and 16% respectively; in addition, the soil parameters obtained through direct shear tests are presented in Table 2. It is highlighted that normal stress is given is terms of total stress.

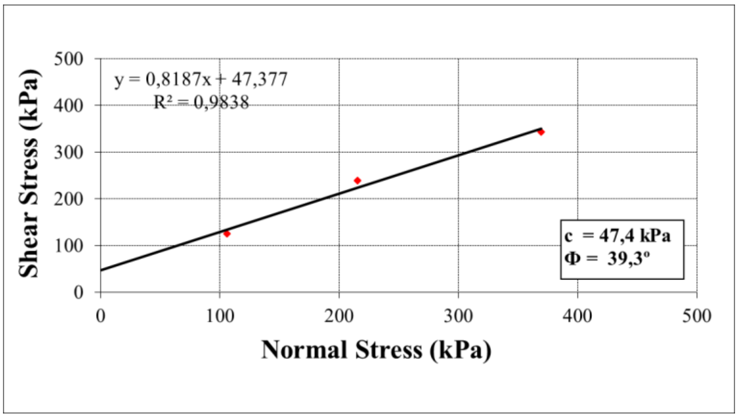

Figure 3: Direct shear curve of the sampled soil compacted with water content equals to 8%

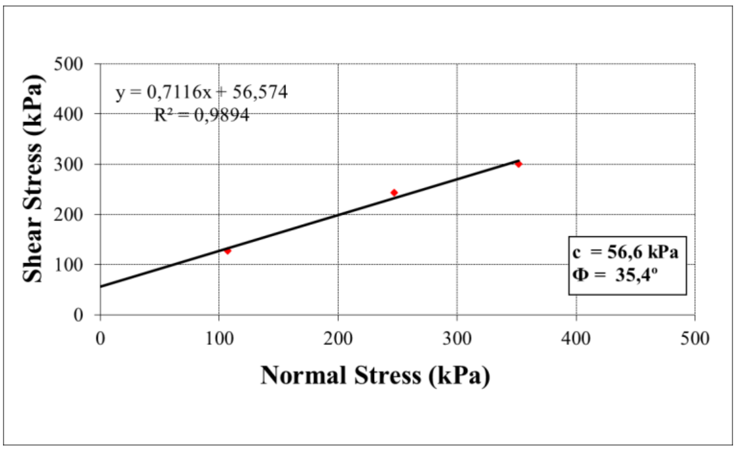

Figure 4: Direct shear curve of the sampled soil compacted with water content equals to 12%

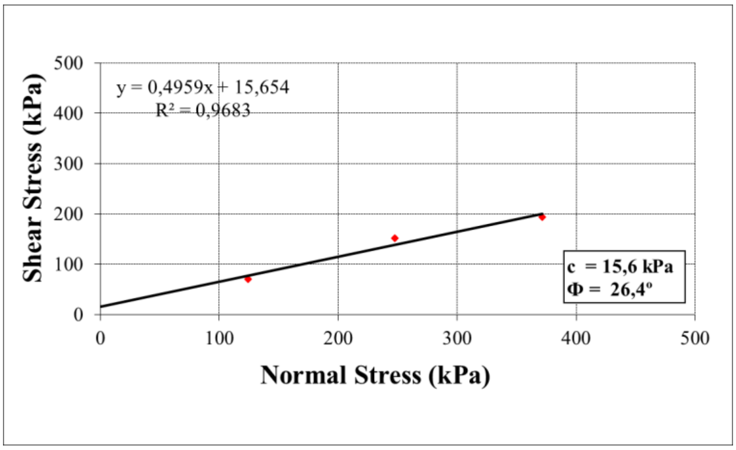

Figure 5: Direct shear curve of the sampled soil compacted with water content equals to 16%

Table 2: Soil parameters from the direct shear test

Water content (%)	Cohesion (kPa)	Internal friction angle (º)
8	47.4	39.3
12	56.6	35.4
16	15.6	26.4

3.2. Experimental results

For the first scenario, the soil parameters were used considering humidity equals to 8 %, Figure 6. This scenario presented a FS of 2.17. In the simulation of the scenario with 12 % humidity, FS was 2.24, Figure 7; while for the soil with 16 % humidity, FS was 1.79, Figure 8.

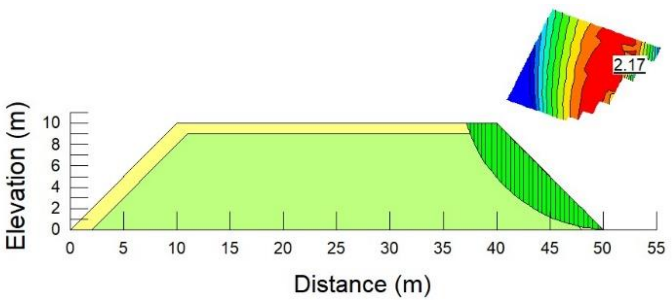

Figure 6: Scenario simulation with soil's water content equals to 8%

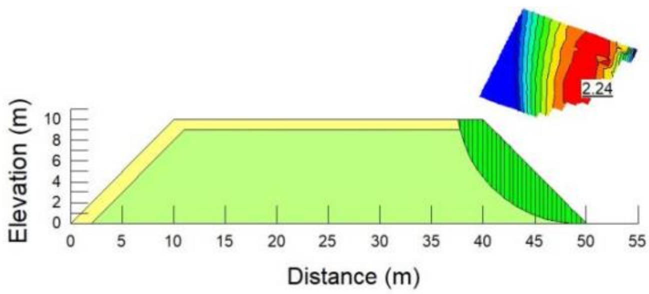

Figure 7: Scenario simulation with soil's water content equals to 12%

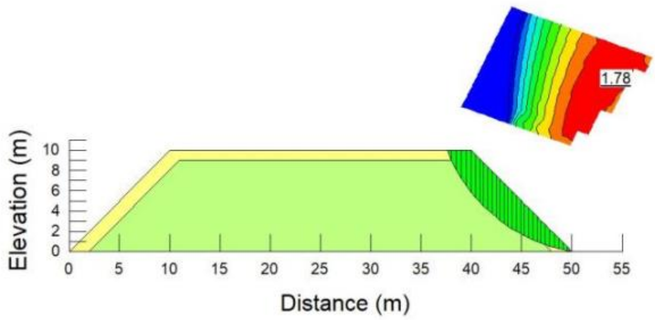

Figure 8: Scenario simulation with soil's water content equals to 16%

In view of this result, Table 3 summarizes soil resistance parameters and their respective FS.

Table 3: Water content (w), cohesion (c), friction angle (ϕ), and FS to the evaluated scenarios

Water content (%)	Cohesion (kPa)	Friction angle (º)	Factor of safety (FS)
8	47.4	39.3	2.17
12	56.6	35.4	2.24
16	15.6	26.4	1.79

It was observed with these results that FS was higher for the soil compacted in optimum water content, which is equal to 12 %. In addition, it is worth noting that the lowest FS was observed for the soil with a humidity of 16 %, 4 % higher than the optimum water content. Figure 9 presents the response of friction in the soil, which was lower for the higher humidity, 16 %. It can also be noted that for the soil with the lowest humidity, 8 %, the soil starts its response at approximately 2 m earlier, involving a greater rupture surface than the other two scenarios.

Analyzing the evolution of the parameters and FS along the scenarios, it can be observed that FS curve behavior followed the evolution of cohesion, Figure 10. Therefore, it can be considered that cohesion had a greater influence on the strength of the scenarios evaluated with the given conditions.

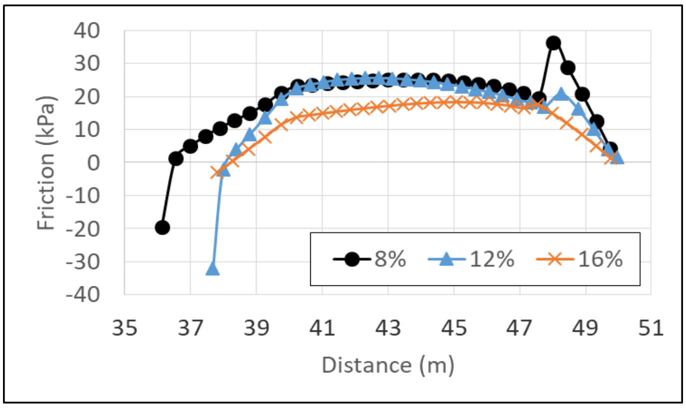

Figure 9: Evolution of soil friction for the evaluated scenarios

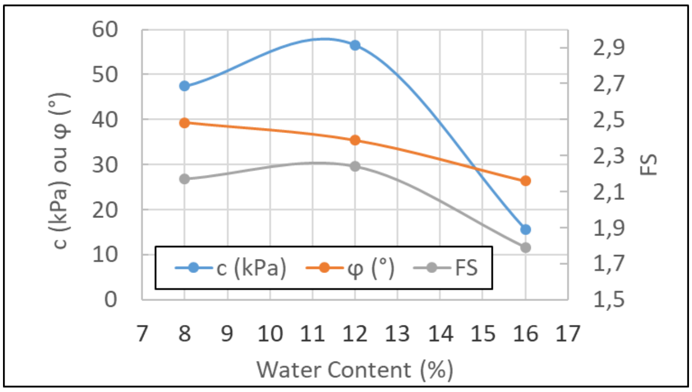

Figure 10: Evolution of cohesion (c), friction angle (ϕ), and FS for the evaluated scenarios

4. Conclusion

In this paper the soil from the MSW landfill cover in the municipality of Altinho - Brazil was studied. This soil was classified as a clayey sandy and its behavior regarding shear strength was evaluated for different values of water content. It was observed that the studied soil presented similar cohesion and FS evolution for the different values of humidity evaluated. In contrast, the friction angle and soil friction reduced as the water content increased. In conclusion, it was observed that the soil presented a higher shear strength when it was at optimal water content.

5. Recommendatios

In this paper, direct shear tests were performed under natural conditions, so it is recommended for future studies to perform this test in flooded conditions in the sample compacted in optimal humidity, since such humidity corresponds to the highest shear strength. Also, complementary studies are suggested, such as suction test, Atterberg Limits, permeability in compacted samples at optimum humidity and ±4 % for better evaluation of the studied soil in terms of its performance as a landfill cover layer.

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