PANAMGEO CHILE 2024
17th PAN-AMERICAN CONFERENCE ON SOIL MECHANICS AND GEOTECHNICAL ENGINEERING | 2nd LATIN-AMERICAN REGIONAL CONFERENCE OF IAEG
LA SERENA • CHILE / NOVEMBER 12 - 16, 2024

Proceedings of the 17th Pan-American Conference on Soil Mechanics and Geotechnical Engineering (XVII PCSMGE), and 2nd Latin-American Regional Conference of the International Association for Engineering Geology and the Environment (IAEG), La Serena Chile, 2024.

Laboratory testing of soil samples for barrier purpose: the Ouro Preto (Brazil) dumping site case

Ensaios laboratoriais em amostras de solos para uso em barreiras selantes: o caso do Lixão de Ouro Preto (Brasil)

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ABSTRACT: Ensuring environmental protection is mandatory for waste containment facilities, such as municipal solid waste (MSW) landfills. Such as the most cities in Brazil, for decades the Ouro Preto MG municipality has dumped its MSW in a close site. It has limited environmental protection measures, including daily cover procedures, paving construction, and isolating the area. Currently, around 40 tons of MSW are being disposed of daily at this site. The lack of base liners likely resulted in groundwater contamination from leachate infiltration. This situation is about to change as legislation will require the municipality to recover and remediate the area. In this context, base liners and cover systems are recognized as critical. Despite the growing application of geosynthetics, compacted clay liners (CCL) and clayey cover systems still play an important role due to economic and technical reasons. This research assesses the suitability of two local soils from this dump site for use in base CCL and cover systems. The first soil sample is original from the site itself. It is a typical clayey reddish lateritic soil of residual origin. Its local volume appears to meet the barrier requirements. The other soil sample came from an embankment placed at the site when a great landslide that took place at the vicinities of the dump in January/2022. It is a grayish green saprolite soil, originated from nearby phyllite rocks. Laboratory tests were carried out for physical characterization and for the determination of the hydraulic conductivity (variable head) of compacted soil specimens (Normal Proctor). The average hydraulic conductivity values were 2.41 x 10^{-7} cm/s for the red lateritic soil and 6.34 x 10^{-6} cm/s for the green saprolite sample. Thus, it is concluded that both samples attend the barrier requirements in terms of geotechnical properties. The red lateric soil is indicated to compose base CCL requirements, while the green saprolite soil may be applied for intermediate and final cover design.

Keywords: compacted clay liner; cover system; hydraulic conductivity; municipal solid waste; dump recovery; clayey soil.

1 INTRODUCTION

Ensuring environmental protection is mandatory for waste containment facilities, such as municipal solid waste (MSW) landfills. As many cities in Brazil, for decades the Ouro Preto MG municipality has dumped its MSW in a nearby site, the so called *Ouro Preto Dump* -OPD (Figure 1). Its operation dated from 1996 to the present, with a total area of 12 acre.

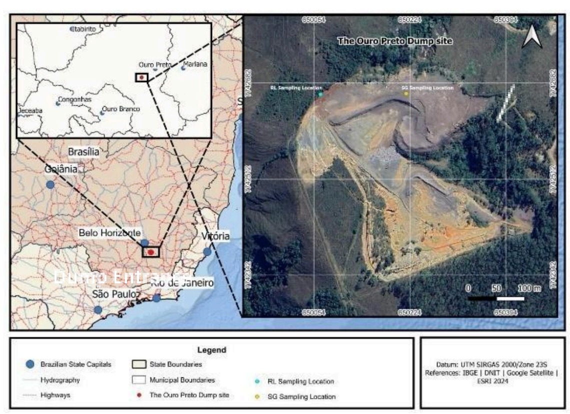


Figure 1: Localization of the Ouro Preto Dump site for municipal solid waste management (Source: Google Earth).

The OPD has limited environmental protection measures, including daily cover procedures, paving construction, and isolating the area. currently, an average of 40 tons of MSW has being disposed of daily at this site. The lack of base liners likely resulted in groundwater contamination from leachate infiltration. This situation is about to change, as the Brazilian Solid Waste National Policy (Law 12.305/2010) will require the municipality to recover and remediate the area.

In this context, base liners and cover systems are recognized as critical issues for environmental protection. Despite the growing application of geosynthetics, compacted clay liner (CCL) and cover systems still play an important role due to economic and technical reasons (Morandini and Leite, 2015, Emmanuel et al, 2019).

This research assesses the suitability of two local soils from this dump site for use in base CCL and cover systems. Laboratory tests were carried out for physical characterization and for the determination of the hydraulic conductivity (variable head) of compacted soil specimens (Normal Proctor).

2 LINER AND COVER SYSTEM REQUIREMENTS

2.1 Compacted Clay Liners (CCL)

Base liner systems can be designed with several layers performing distinct functions each, such as separation, impermeabilization, drainage etc. As part of these systems, compacted clay liners (CCL) usually provide the last barrier for leachate infiltration towards groundwater (Daniel, 1993, Rowe et al., 2004, Boscov, 2008), as shown in Figure 2.

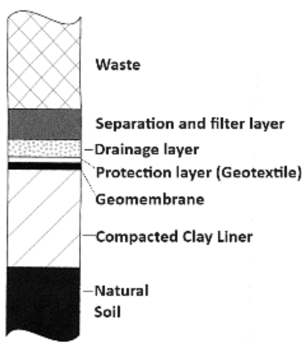


Figure 2 – Multilayered bottom barrier system for solid waste containment (modified from Boscov, 2008).

Some technical advantages of CCL may include the low hydraulic conductivity of engineered clayey soils and the relatively high sorption and self-healing capacities. Also, their construction methods and operation are well consolidated worldwide (Rowe et al. 2004, Boscov, 2008).

Disadvantages include the high volume of material, which sometimes are not available on the site itself, superficial dry-cracking when exposed to the atmosphere and the potential incompatibility of some clay mineral to some concentrated organic and inorganic liquids, which is usually not the case for MSW leachate (Daniel, 1993; Sharma and Lewis, 1994; Boscov, 2008; Leite and Morandini, 2018).

When designing a bottom CCL barrier, several factors need to be taken into consideration. These include hydraulic conductivity, shear strength, geometry, liner protection, and compatibility with local leachate (Leite, 2001, Katsumi et al, 2008, Morandini and Leite, 2018). Since the CCL is not to be overstressed when dealing with low-density municipal solid waste (MSW), simple clay compaction under Normal Proctor energy is usually sufficient to ensure shear strength demands. However, the specific requirements for geometry, protection, and compatibility with local leachate will vary depending on the site.

There is a consensus about the minimum value required for the hydraulic conductivity as $K = 10^{-7}$ cm/s (Acar and Olivieri, 1989; Benson and Daniel, 1990; Chapuis, 1990; Daniel and Wu, 1993; Rocca et al.,1993; Shackelford,1994; Benson et al.,1994; Bagchi,1994; Anderson and Hee,1995; Rowe et al., 1996; Sharma and Lewis, 1994; Gleason et al., 1997 and U.S. EPA, 2004, Met and Akgun, 2015, Umar et al, 2015, Morandini and Leite, 2018). Finding local soils that meet this requirement is challenging and increasing the CCL thickness can be an alternative. Soils with $K = 10^{-6}$ cm/s can be considered safe if it is recommended by a proper contaminant transport numerical simulation.

2.2 Cover Systems

As part of the MSW landfill closing procedure, the final cover system is aimed to minimize water infiltration (barrier), limit uncontrolled release of inner gases, suppress vector proliferation, limit fire potential, and provide an adequate surface for site revegetation to avoid erosion (Tchobanoglous and Kreith, 2002, Wan et al, 2018).

To fulfill these demands, several layers are specifically designed, including the barreir layer. This layer will reduce the leachate generation inside the MSW deposit, and, therefore, the hydraulic conductivity is the main property to be controlled. Clayey soils and/or synthetic geoembranes are usually the materials of choice due to their well reconized low intriltration capacity.

Other important property of the clayey barriers is their partial self-healing capacity when punctured or subject to small tensile stress. Due to the high MSW consolidation, landfill covers are frequently affected by differential settlements (Sharma and Lewis, 1994), resulting in craking and erosion features.

3 MATERIALS AND METHODS

3.1 Soil Collection and Characterization

Two disturbed soil samples were collected for the laboratory tests, and the sampling locations are depicted in Figure 3.

Figure 3 – Sampling locations (Source: Ouro Preto City Hall, Environmental Quality Department)

The first soil sample was collected at a depth of 1 m from a slope outcrop located at the north boundary of the Ouro Preto Dump site (Figure 4a). Around 200 kg of disturbed soil was collected and placed in plastic bags. It is a typical clayey reddish residual lateritic soil and will be referred to as "LR Sample". As can be seen in Figure 3, this sample was collected in the northern plateau of the dump, which may extend northward to higher altitudes.

The other soil sample was collected on the surface of an embankment close to the north boundary of the OPD site (Figure 3 and Figure 4b). This embankment was formed from rock and soil debris resulting from a large landslide that occurred on the slopes of the roadway MG 129 in January/2022, approximately 2 km of this dump. It is a grayish green saprolite from phyllite rocks and will be called here as "SG Sample".

(a)

(b)

Figure 4: *(a) Reddish lateritic soil (LR Sample) collection on a slope outcrop; (b) Grayish green saprolite (SG Sample) collection on the northern embankment (Source: Authors).*

According to the standard ABNT-NBR 6457 (2016), the samples were initially dried at room temperature, then sieved, homogenized, and reduced using a regular soil splitter. Table 1 provides a summary of their key physical properties.

Basically, the LR sample is composed of clay and silt fractions. Even though this sample has a significant clay content of 37%, its plasticity index is relatively low (PI = 16%), resulting in its classification as ML (refer to Table 1). This is a common feature of soils with high laterization levels, where the fine fractions are predominantly composed of minerals with low plasticity, such as kaolinite and Fe-Al oxides/hydroxides. The SG sample is mainly composed of silt (39.7%), gravel (27.9%) and clay (8.8%). Since this sample has no plasticity, the clay fraction is likely made up of quartz, feldspar and mica, which is common for these phyllite rocks.

The saturation process for hydraulic conductivity testing, one of the key objectives of this research, is known to be time-consuming for compacted clay samples using the standard Normal Proctor (NBR 7182/2016) energy. To accelerate this process, some miniature compacted soil specimens were manufactured using the "Mini Proctor" procedure suggested by the standard DNER-ME 228 (1994). The optimum moisture content of the standard Normal Proctor was applied. The final size of these soil specimens was close to 5 cm in length and 5 cm in diameter and their compaction parameters are also depicted in Table 1. It can be observed similar maximum dry density (ρ_d) values when compared to the standard Normal Proctor test results.

Table 1. *Laboratory Characterization Tests.*

	Sample		
Property	**LR**	**SG**	**Reference**
Density of solids ρ_s (g/cm^3)	2.947	2.884	NBR 6458
Grain Size Distribution (%)			NBR 7181
Clay < 0.002 mm	37	8.8	NBR 6508
Silt (0.002 to 0.6 mm)	20	39.7	
Fine Sand (0.6 to 0.2 mm)	15	14.5	

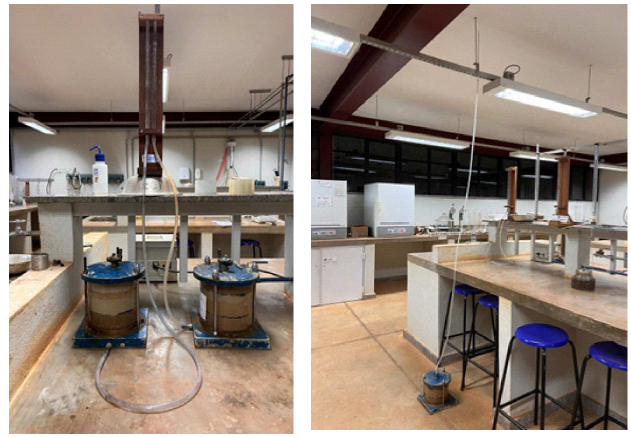
Medium Sand (0.2 to 0.6) mm	22	9.0	
Coarse Sand (0.6 to 2.0) mm	5.6	0.7	
Gravel (2.0 to 60 mm)	0.4	27.3	
Plastic Limit, w_p (%)	28	NP	NBR 7180
Liquid Limit, w_L (%)	44	40	NBR 6459
Plastic Index, PI (%)	16	0	
USCS	ML	ML	ASTM D2487
Normal Proctor			NBR 7182
Optimum water content, w_{ot} (%)	25.65	24.98	
Maximum dry density, ρ_d (g/cm^3)	1.608	1.623	
Mini Proctor			DNER-ME 228
Optimum water content, w_{ot} (%)	25.60	25.00	
Maximum dry density, ρ_d (g/cm^3)	1.653	1.521	

3.2 Hydraulic Conductivity Test

Variable head hydraulic conductivity tests were performed in duplicate according to the standard ABNT NBR 14545 (2021-Method B) using Mini Proctor samples, as mentioned in the precedent item.

Samples were saturated by percolation from the bottom to the top under variable head conditions. This process was completed when water apported at the upside valve of the permeameter cell. Figure 5a depicts the saturation process for the SG samples on the hydraulic conductivity cells, which lasted for 7 days. As the LR samples were taking too long to saturate, the hydraulic head was raised, reaching the roof of the laboratory (Figure 5b), when a hydraulic gradient of sixty was stablished. It has proved to be insufficient, since the samples have remained unsaturated after two months.

To overcome the saturation issue with the LR sample, a different approach was used. Two cylindrical soil specimens, each measuring 2 cm in high and 8 cm in diameter, were compacted using Normal Proctor energy on a consolidation cell (Figure 6a). Then, they were saturated according to the standard ABNT-NBR 16853 (2020), which suggests a variable head apparatus, as shown in Figure 6b. By implementing this procedure, the saturation period was reduced to 3 days.



(a) (b)

Figure 5: *Sample saturation on the variable head apparatus: (a) SG sample; (b) LR sample saturation using a high elevation head approach.*

(a) (b)

Figure 6: *(a) LR soil specimen of 2.0 cm high and 8.0 cm in diameter compacted on a consolidation cell; (b) Variable head hydraulic conductivity determination on the consolidation cell apparatus.*

Four compacted/saturated samples, two SG (5 cm in high and 5 cm in diameter) and two LR (2 cm high and 8 cm in diameter) were submitted to variable head percolation for the hydraulic conductivity estimation. Hydraulic gradients of 2 to 15 were applied for these tests, as suggested by the standard ABNT-NBR 14545/21. Seven estimates were made for each soil specimen, totalizing twenty-eight measures.

4 Results and Discussion

Table 2 displays the suitability of the samples for barrier usage based on index properties criteria found in the literature. The LR sample met most of criteria, except for a higher clay content than expected. The SG sample, did not meet the criteria for clay fraction and plasticity index.

Table 2. *Index properties suitability for barrier purpose.*

Reference	Criteria	LR Sample	SG Sample
Fine Fraction (ø < 0.075 mm)			
Rocca et al. (1993)	≥ 30%	57.0% (OK)	48.5% (OK)
U.S. EPA (2004)	≥ 30%	57.0% (OK)	48.5% (OK)
Bagchi (1994)	≥ 50% (Acceptable 40% to 50%)	57.0% (OK)	48.5% (OK)
Clay Fraction (ø < 0,002 mm)			
Rowe et al. (1996)	15 to 20%	37.0% (Not OK)	8.8 % (Not OK)
Bagchi (1994)	≥ 25% (Acceptable 18% to 25%)	37.0% (Not OK)	8.8 % (Not OK)
Liquid Limit			
Benson et al. (1994)	≥ 20%	44.0% (OK)	40.0% (OK)
Rowe et al., (1996)	≥ 20%	44.0% (OK)	40.0% (OK)
Bagchi (1994)	≥30% (Acceptable 25 to 30%)	44.0% (OK)	40.0% (OK)
Rocca et al. (1993)	≥30%	44.0% (OK)	40.0% (OK)
U.S. EPA (2004)	≥30%	44.0% (OK)	40.0% (OK)
Plasticity Index			
Benson et al. (1994)	≥ 7%	16.0% (OK)	NP (not OK)
Rowe et al. (1996)	≥ 7%	16.0% (OK)	NP (not OK)
Rocca et al. (1993)	≥ 15%	16.0% (OK)	NP (not OK)
Bagchi (1994)	≥ 15% (Acceptable 10 to 15%)	16.0% (OK)	NP (not OK)

Table 3 shows the hydraulic conductivity (*K*) arithmetic average for both compacted soil samples. According to the criteria discussed on the Section 2.1, the LR sample is suitable for CCL application since its average hydraulic conductivity is in the order of 10^{-7} cm/s.

Table 3. *Average hydraulic conductivity test results, K (cm/s).*

Soil Sample	Test 1	Test 2	Average
LR	2.4×10^{-7}	2.3×10^{-7}	2.4×10^{-7}
SG	6.3×10^{-6}	6.3×10^{-6}	6.3×10^{-6}

In turn, the SG sample did not meet this criterion, presenting an average *K* in the order of 10^{-6} cm/s. As discussed in Section 2.1, this value can be suitable once the barrier thickness is increased, but this solution must be supported by a suitable hydrological and contaminant transport modelling, which is site specific. As this material is available in large quantities at the OPD site, it is suggested to use it for daily, intermediate and final cover designs.

5 CONCLUSIONS

Two compacted soil samples have been evaluated for barrier application at the Ouro Preto MSW Dump site. Both samples came from the site itself, which is very convenient.

In terms of index properties and hydraulic conductivity, the reddish lateritic soil (LR Sample) has proven to be suitable according to most of the literature criteria, which opens the perspective of using it as compacted clay liner and/or cover system.

In turn, the SG sample has shown to be inadequate in terms of plasticity and hydraulic conductivity. As this material is readily available in the site and has a *K* value in the order of 10^{-6} cm/s, it is suggested to used it for daily/intermediate and/or final cover designs.

ACKNOWLEDGEMENTS

The authors really appreciate the NUGEO Soil Mechanics Laboratory staff for their contribution to the laboratory testing procedures and the Ouro Preto Municipality staff for their support on this research. The reviewer's comments significantly enhanced the manuscript, and we are truly thankful to him.

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