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Assessment on Physico-Chemical Properties for Granite Residual Soil as Landfill Liner Material at Batu Pahat, Johor, Malaysia

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Abstract

Soil samples from Batu Pahat, Johor, Malaysia, were tested for their physico-chemical properties. Results show the local granite soil has hydraulic conductivity less than 1×10^{-7} cm/s, compressive strength between 230 and 450 kPa, and shrinkage potential less than 4%. These values satisfy the DOE minimum requirements for landfill compact clay soil liner.

Keywords: Granite soil, physico-chemical properties, landfill compacted clay soil liner.

1. Introduction

Most landfills today use plastic or clay as liner materials. The purpose is to prevent groundwater contamination from landfill leachates. In our country, clayey soil, compact or otherwise (natural), is commonly used because it is cheap, easily available and has low permeability. Most landfills in Malaysia are located in Selangor and Johor. The former has only two landfills out of eleven that comply with the Department of Environment (DOE) liner requirements [1]. The latter has about thirty landfills but only fifteen are engineered.

There are many types of materials now in use for landfill liner but commonly, it is clay combined with geo-synthetic materials, termed geo-synthetic clay liner (GCL). Due to its natural earth (clay) content, GCLs are susceptible to chemical attack by leachates and the extent of damage caused by a poorly performing liner depends on the ability of the acids/bases and/or the neutral inorganic/organic liquids to react on the clay particles while passing through them. Normally a clay liner fails for two reasons, either the clay material has not been studied enough, or there is no proper control of the liner during construction. In the circumstances, the liner would dry and crack as a result of shrinkage [2]. A good liner should have at least 30% fines [3&4], 15% clay [4], and at least 10% plastic index (PI) but not exceeding 25% [5] with liquid limit (LL) less than 45% to ensure the much desired low hydraulic conductivity (K) of less than 1.0×10^{-7}cm/s. The soil should have high compressive strength, preferably higher than 200 kPa with low shrinkage potential (less than 4%) [6]. Hydraulic conductivity is simply the soil's permeability while shrinkage is its ability to crack. Study of the physico-chemical properties of the soil should provide insight into the soil's capability to absorb heavy metals commonly found in landfills while the hydraulic conductivity, strength, potential for shrinkage, and moisture content are tied directly or indirectly to compaction [3].

2. Materials and Methods

A number of three soil samples, collected from two 0.5m deep auger holes, each at Minyak Beku (MB) and Batu Tiga (BT)) in Batu Pahat, Johor, Malaysia, were analyzed based on British Standards [7] for the physical parameters and Manual of Soil Laboratory Testing [8] for the chemical parameters. The test parameters (Table 1) follow the work of Ridwan et. al. [9] in which the researchers established that the parameters control the soil's ability to absorb heavy metals. The reasons why we choose to study granite soil instead of other soil types are twofold: first, granite has potential as landfill liner material; and second, it is easily available in Batu Pahat.

3. Results and Discussion

Test results (Table 1) confirm the soil from the borrow sites is granite with average specific gravity 2.62. MB soil comprises 50% clay, 40% sand and 10% silt while BT soil is 45% clay, 30% sand, 10% silt, and 15% gravel. The soil is cohesive (MB soil has 60% fines and BT soil 55% fines), surpassing the 30% fines minimum requirement as recommended by Daniel [10] and Benson et. al.[4]. The soil also

Table 1: Soil test results

Location	**Minyak Beku (MB)**			**Batu Tiga (BT)**		
Parameter	**1**	**2**	**3**	**1**	**2**	**3**
Symbol	■	●	▲	□	○	△
W_o	23.21	23.35	22.22	21.97	23.82	23.39
G_s	2.62	2.60	2.61	2.49	2.60	2.44
Clay %	50	45	56	46	34	47
Silt %	12	13	6	10	9	9
Sand %	38	42	38	31	38	32
Gravel %	0	0	0	13	19	12
LL %	64	62	62	71	72	79
PL %	28	28	28	34	33	32
PI %	38	35	34	37	39	47
Classification of soil	CH	CH	CH	MV	CV	CV
W_{opt} %	20.20	22.30	25.10	23.00	20.60	-
Γd_{max} (kg/cm^3)	1615	1535	1445	1465	1499	-
K (cm/s)	2.0×10^{-8}	3.0×10^{-8}	4.0×10^{-8}	1.0×10^{-8}	1.0×10^{-8}	-
Shrinkage limit %	3.02	2.98	-	3.11	3.27	-
Shear strength (kPa)	225.2	430.87	-	396.66	346.68	-
pH	4.58	4.64	4.83	4.66	4.70	4.73
SSA (m^2/g)	369.42	-	-	220.89	-	-
Clay content	I	I	Kl	I	I	I

Note: Gs = Specific gravity; LL = Liquid limit; PL = Plastic limit; PI = Plastic index; W_{opt} = Optimum moisture content; γd_{max} = Dry density; k = Permeability; Kl = Kaolinite; I = Illite; CH = Clays of high plasticity; MV = Silts of very high plasticity; CV = Clays of very high plasticity; SSA = Specific surface area.

satisfies the 15% clay minimum requirement as recommended by Benson et. al. [4]. The soil has low shrinkage potential (less than 4%) so its ability to crack is small, given proper control during construction. The soil's compressive strength is high (225-430 kPa), well above the commonly accepted limit of 200 kPa [6]. According to Benson et. al. [4], soils with high LL tend to have low K. Our soil LL is in the high range (60-80%) and this has caused the K value to be 1/10 to 4/10 times less than the suggested upper limit of 1.0×10^{-7}cm/s [6]. The MB soil PI is in the 34-38% range whereas the BT soil PI is in the 37-47% range. PI and LL data were plotted in the plasticity chart (Figure 1) and using the graph, we classify MB soil and BT soil as CH (clay with high plasticity) and CV (clay with very high plasticity) respectively. It is noted that soils with high plasticity generally have low permeability but high compressibility. Between CH and CV soils, CH soils are more suitable for use as landfill compacted clay liner [11]. It is observed in Figure 1 that all of the plotted points fall above line A except for sample BT1. This indicates that the soil is suitable for use as landfill clay material [12]. As for chemical analyses, the soil pH is acidic (4.5-4.8), which agrees closely with the observation of Wan Yaacob et. al. [13] for the granite residual soil. As with marine clay, their pH 7.3 to 7.6 is more alkaline than our soil. Soils with high pH tend to absorb more heavy metals as metal precipitation increases with hydroxides and oxides and carbonate materials [3]. Also, our soil has specific surface area (SSA) in the 220-370m^2/g range, which is 1-2 times higher than the marine clay SSA observed by Wan Yaacob et. al. [13]. The reason our SSA is higher is due to our 35-50% clay content being higher compared to their 14-24% clay content (for marine soil) and 2-7% clay content (for granite residual soil). Following further their reasoning, we deduce that our soil has 1 to 2 times more potential to absorb heavy metals than their marine clay, which is in agreement with their conclusion that soil sorption capacity for heavy metals increases with increasing SSA.

As with soil mineralogy, William [14] pointed out that soils with SSA 600-800 m^2/g have predominantly monmorillonite mineral whereas soils with SSA 5-20 m^2/g have kaolinite and illite dominating. Since our soil SSA is from 220m^2/g (BT) to 370m^2/g (MB), we deduce our soil mineralogy falls between monmorillonite and kaolinite and illite combined. Our analysis shows moderate clay activity does exist in our soil, which is proof that illite mineral dominates. This is shown in the plot of the position of the five samples (Figure 2) although the MB3 sample singles out in the low activity region, suggesting the presence of kaolin. High clay activity, according to Skempton [15], infers that monmorillonite mineral dominates. This confirms further the 35-50% moderate clay content indicates the presence of illite in the soil. We could have a better picture of the soil properties had we analyzed heavy metals, capacity exchange cations (CEC), soil microstructure using scanning electron microscope (SEM), and major chemical elements using X-ray diffractometer (XRD).

The study shows our local granite soil is non-homogeneous and is suitable for use as landfill compacted liner material in terms of hydraulic conductivity, strength, and potential for shrinkage. Between the two borrow sites, MB soil is more suitable.

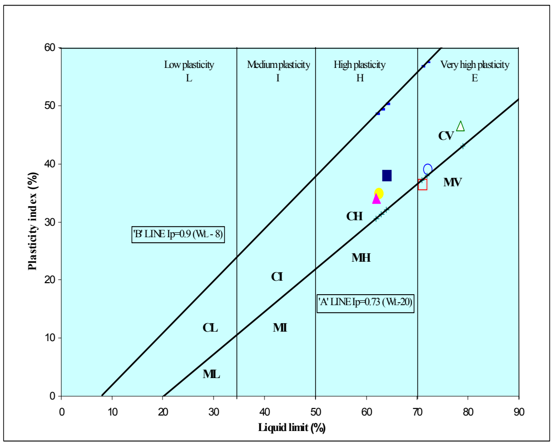

Figure 1: Plastic index vs. liquid limit.

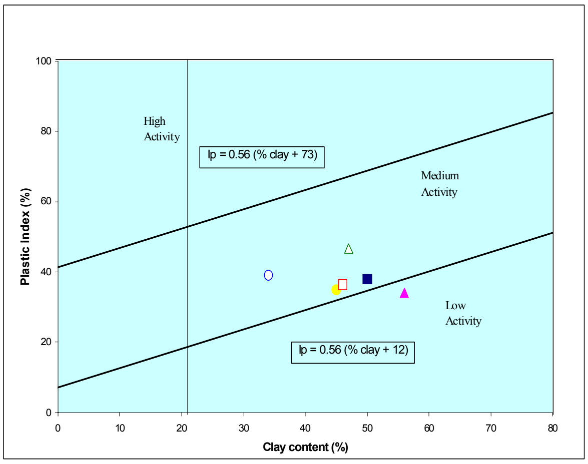

Figure 2: Plastic index vs. clay content

4. Conclusion

The study shows the local granite soil is non-homogeneous and predominantly illite, and satisfies the DOE minimum requirements as landfill compacted clay soil liner in terms of hydraulic conductivity, strength, and potential for shrinkage.

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