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Viability of Kauswagan Clay as Landfill Liner

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Abstract: The study is on the viability of clay sample from Kauswagan, Lanao del Norte as sanitary landfill liner. Lining system along with leachate collection and treatment system, landfill gas collection and treatment system, daily cover, final closure and ecological remediation, are among the key aspects in design and implementation in a sanitary landfill. The liner system will prevent landfill gas and leachate to contaminate the surrounding soil and water, so the amount of leachate can be controlled. Clay minerals have been used as an important ingredient in landfill liners due to its high sorption capacity, long-term structural stability, and low permeability. Compacted clay is widely used in sanitary landfill lining system alone or with high-density polyethylene (HDPE). The preliminary investigation to ensure that the soil sample is clay covered the physical properties including grain-size distribution, Atterberg limits, specific gravity, maximum and minimum index densities, soil classification and compaction behavior. The main experimentation is on the hydraulic conductivity test of clay sample with 20% fines content at varying relative density which is related to void ratio. The soil sample is specifically classified as sandy inorganic fat clay in accordance with the Unified Soil Classification System (USCS). An equation was formulated that can predict hydraulic conductivity as a function of the void ratio. From the formulated equation, the void ratio corresponding to the required hydraulic conductivity can be determined. The void ratio is related to the dry unit weight. Using relative degree of compaction, the degree of required compaction can be applied in the field given the in situ void ratio.

Key Words: Kauswagan clay; Landfill liner; Hydraulic conductivity; Sanitary landfill

1. INTRODUCTION

Republic Act 9003 otherwise known as "Ecological Solid Management Act of 2000" The law mandates all local government units (LGUs) to transition from open dump site to controlled dump site, and eventually to a sanitary landfill.

Sanitary landfill is an engineered containment system to handle refuse, garbage, and domestic wastes designed to provide pollution control measures (Koerner et. al, 2002). Lining system, leachate collection and treatment system, landfill gas collection and treatment system, daily cover, final closure and ecological remediation, are among the key techniques that must be considered in design and implementation. The liner system will prevent landfill gas and leachate to contaminate the surrounding soil and water, and thus the amount of leachate can be controlled (Youcai and Ziyang, 2017).

For many landfill leachates, heavy metals are often found that are toxic to the environment and to human health (Bove et al, 2015). Leachate may move out of the landfill by advection and diffusion processes. It is apparent that the anti-seepage and contaminant sorption capability of liners is crucial for the design of a landfill.

Clay minerals have been used as an important ingredient in landfill liners due to its high sorption capacity, long-term structural stability, and low permeability. Compacted clay is widely used in sanitary landfill lining system alone or with high-density polyethylene (HDPE) (Kaya and Durukan, 2004).

Hydraulic conductivity also called coefficient of permeability is the property of a soil that allows the seepage of fluids through its interconnected void spaces (Das, 2008). This property is very critical in the liner leakage mechanism of the sanitary landfill. Leachate consists of the water and solutes or dissolved substances. The solutes may flow with the direction of water in response to a gradient in hydraulic head (advection) or from region of high to low concentration (diffusion). Regulatory bodies set hydraulic conductivity usually $1x10^{-7}$ cm/sec to manage leakage. Diffusion becomes increasingly important leakage pathway in cases of barriers with very low hydraulic conductivity (Koerner et. al, 2002).

The IRR of RA 9003 requires hydraulic conductivity or permeability to be a maximum of $1x10^{-6}$ cm/sec for soil liner.

The municipality of Kauswagan and the nearby municipalities will have to operate a landfill and thus necessary will have to source out clay as liner. This study was conducted to determine the viability of using the locally available clay soil as landfill liner. Its physical properties and hydraulic conductivity characteristics have to be known to assess its effectiveness as landfill liner material.

2. METHODOLOGY

2.1 Research Design

The study used experimental method in the evaluation of the soil sample. Laboratory tests in accordance to American Society for Testing and Materials (ASTM) standards as well as procedures proposed in related studies and soil mechanics books. Safety measures were observed in the course of the tests.

2.2 The soil sample

The disturbed soil sample was taken from Kauswagan, Lanao del Norte from the northern part of the Philippines, the island of Mindanao. The soil was taken at a depth of at least a meter and appeared to be reddish brown. Figures 1 and 2 show the moist and dry soil sample.

Fig. 1. Moist Soil Sample

Fig. 2. Oven-dried Soil Sample

2.3 Preliminary Investigation

The preliminary investigation covered the physical properties covering the grain-size distribution (mechanical and hydrometer analysis), Atterberg limits (plastic limit, liquid limit, shrinkage limit and shrinkage ratio), specific gravity, maximum and minimum index densities, soil classification and compaction behavior which is described in terms of optimum moisture content and maximum dry unit weight. The study of the micro fabric or microstructure of the soil sample was done through Scanning Electron Microscopy (SEM) to check on features like particle arrangement, particle assemblage and pore spaces. The experimental program is summarized in Table 1 with the corresponding references.

Table 1. Preliminary Experimental Program

Test	Standard Reference
Grain Size Analysis (Mechanical and Hydrometer Method)	ASTM D422
Specific Gravity Test	ASTM D854
Liquid Limit Test	ASTM D4318
Plastic Limit Test	ASTM D4318
Shrinkage Limit Test	ASTM D427
Minimum Index Density Test	ASTM D4254
Maximum Index Density Test	ASTM D4253
Compaction Test (Proctor Method)	ASTM D698
Scanning Electron Microscopy	

2.4 Main Experimentation

The main test conducted was on the hydraulic conductivity of the soil sample passing sieve no. 40. The general procedure was patterned after that proposed by Liu and Evett (2000). Tests were conducted on reconstituted sample prepared by moist tamping method at varying relative density (0 to 100%) at constant fines content of 20 percent. Fine content is defined as the soil grains passing the No. 200 sieve. The falling-head test was conducted in a rigid-wall permeameter under a hydraulic gradient of 4. Measures to ensure full saturation of the soil sample were put in place for a thorough distribution of water. Temperature was taken for viscosity correction. The hydraulic conductivity is computed using equation 1 with the data collected. The output of the test is presented in a semi-log plot, the hydraulic conductivity in a logarithmic scale and the void ratio in arithmetic scale, showing the relationship between void ratio and hydraulic conductivity. The plot in is a useful aid to predict the value of in-situ hydraulic conductivity of the soil if the in-situ void ratio is known.

$$k = \frac{2.3aL}{At} log \frac{h_1}{h_2} \qquad \text{(Eq. 1)}$$

where:

- k = hydraulic conductivity in cm/sec
- a = cross-sectional area of the burette in cm^2
- L = length of soil sample in cm
- A = cross-sectional area of soil specimen in cm^2
- t = total time for the water in burette to drop from h_1 to h_2 in sec
- h_1 = hydraulic head at the beginning of test in cm
- h_2 = hydraulic head at the end of test in cm

3. RESULTS AND DISCUSSION

3.1 Grain-Size Analysis

The test resulted to a soil sample which is 5.6 % gravel, 42.3 % sand and 52.1% fines. The behavior of the curve as shown in Fig. 1 reveals a somewhat gap graded soil.

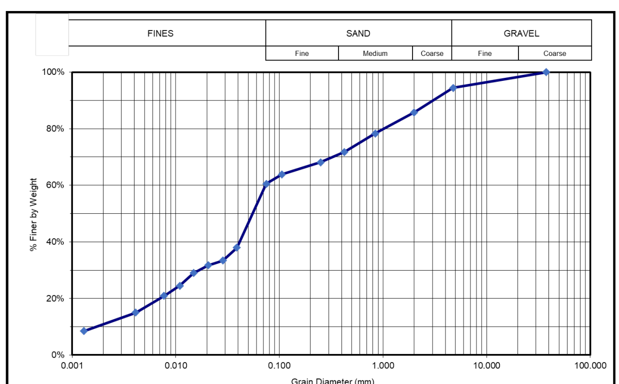

Figure 1: Grain-Size Analysis Curve

Fig. 3. Grain-size Distribution Curve

3.2 Soil Constants

The series of test resulted to values as shown in Table 1 for the soil constants. The values for liquid limit and plasticity index are important inputs for soil classification.

Table 1. Soil Constants

Soil Property	Experimental Value	Expected Values (Budhu, 2011)
Specific Gravity, Gs	2.71	2.70-2.80
Plastic Limit, PL,	34.80	25-50
Liquid Limit, LL	60.00	40-150
Plasticity Index, PI	25.20	15-100
Shrinkage Limit, SL	30.92	-
Shrinkage Ratio, SR	1.33	-
Max. Void Ratio, e_{max}	1.79	-
Min. Void Ratio, e_{min}	0.92	-
Max. Dry Unit weight, γ_{dmax}	11.36 kN/m^3	-
Min. Dry Unit weight, γ_{dmin}	9.56 kN/m^3	-
Dry Unit Unit weight, γ_{dmax}	11.40 kN/m^3	14-21 kN/m^3
Optimum Moisture Content, ω	31.22 %	-

The result values of the test for specific gravity, plastic limit, liquid limit and plasticity index all fall within the range of expected values for clay.

3.3 Soil Classification

The soil sample is classified as sandy inorganic fat clay in accordance to the Unified Soil Classification System (USCS) using the percent finer passing No. 200, liquid limit, plasticity index, percentage passing of sand and gravel.

3.4 Compaction Characteristics

For a given compactive effort, there is a corresponding moisture content at which the dry unit weight is greatest and compaction is optimum. The moisture content is known as the optimum moisture content and the associated dry unit weight is called the maximum dry unit weight, values of which are reflected in Table 1. The moisture versus unit weight relationship is characterized by a concave downward curve shown in Figure 4 with the optimum water content of 31.22 % corresponding to a maximum dry unit weight of 11.40 kN/m^3. This is a typical result for elastic silty clays. Clay soils exhibit very high optimum moisture content at a low maximum dry unit weight (Liu & Evett, 2001).

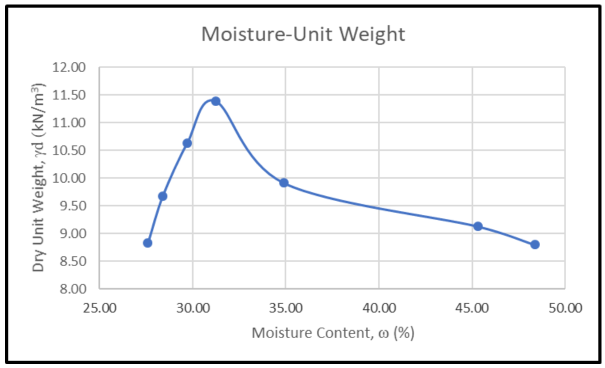

Fig. 4. Compaction Curve

3.5 Scanning Electron Microscopy

The SEM test images in figure 5 and 6 show the over-all impression especially the former image of 7500 magnification shows that a fractured surface of a pelletized clay.

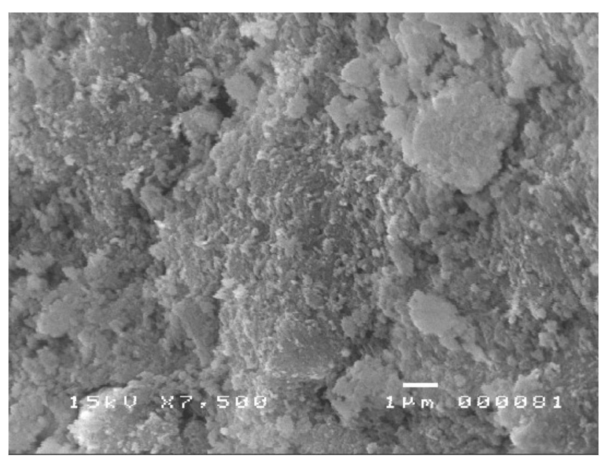

Fig. 5. SEM Image of Soil Sample at 7500 Magnification

The soil contains many components such as clay minerals, clay accessory minerals and organic materials. Most of those have common shapes and size ranges. Soil exhibits very small inter granular voids and flocculation with flakey particles usually associated to clay.

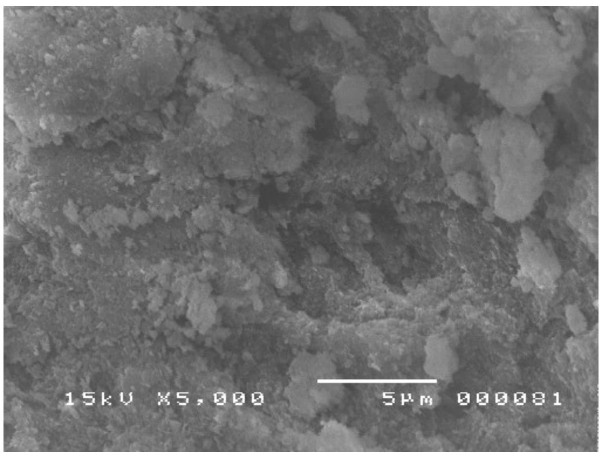

Fig. 6. SEM Image of Soil Sample at 5000 Magnification

3.6 Hydraulic Conductivity

The result of the hydraulic conductivity test ranges from $1x10^{-5}$ to $1x10^{-7}$ cm/sec as shown in figure 7 which can be considered to have low to very low hydraulic conductivity typical to a silty clay. The output of the test is presented in a semi-log plot, the hydraulic conductivity in a logarithmic scale and the void ratio in arithmetic scale, showing the relationship between void ratio and hydraulic conductivity in figure 7.

Equation 2 provides a model wherein hydraulic conductivity can be predicted as a function of the void ratio with the fine contents set at a constant of 20%. From the formulated equation, the void ratio can be determined to produce the hydraulic conductivity meeting the requirement for sanitary landfill liner.

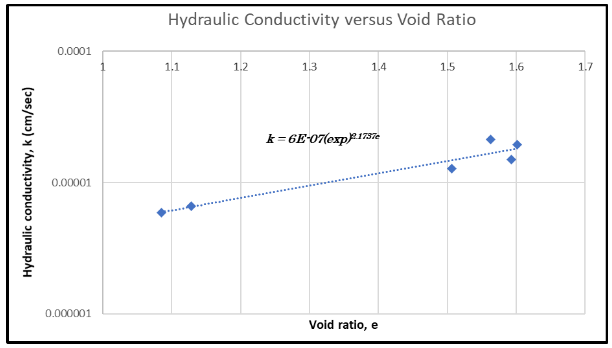

Fig. 7. Hydraulic Conductivity versus Void Ratio Plot

The void ratio is related to the dry unit weight. Using relative degree of compaction, the required degree of compaction can be applied in the field given the in situ void ratio.

$$k = 1 \ x \ 10^{-7} exp^{2.1737e} \qquad \text{(Eq. 2)}$$

where:

k = hydraulic conductivity in cm/sec

e = void ratio

The equation developed for hydraulic conductivity as a function of void ratio only is limited to this particular soil sample under study and at 20 % fines. This is a simplified version to that equation where the hydraulic conductivity is both a function of void ratio and fines (Adajar and Zarco, 2014).

4. CONCLUSIONS

The soil sample from Kauswagan is identified to be clay based on its physical properties Further, the SEM images supported the tests conducted to ascertain that the sample is clay. The hydraulic conductivity test using the falling head test yielded values of hydraulic conductivity considered to be of very low conductivity suitable for land fill liner material.

An equation relating the hydraulic conductivity and the void ratio was formulated. The value of field hydraulic conductivity can be predicted given the in situ void ratio. Upon application of the proper degree of compaction to reduce void ratio, the required hydraulic conductivity as per RA 9003 can be sufficiently met.

5. ACKNOWLEDGMENTS

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