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EFFECTS OF SOIL RECOMPACTION ON PERMEABILITY

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ABSTRACT
Presence of water changes the properties of soil such as dry density, shear strength, swelling-shrinkage and permeability. In this research, the effects of recompaction on permeability of laterite soil extracted from the Faculty of Engineering in Universiti Teknologi Malaysia was investigated in the design of liners and covers used as hydraulic barriers in sanitary landfills. Landfill liner needs to have sufficiently low permeability value so that it impedes migration of leachate through the compacted soil which causes groundwater contamination. The falling head permeability method of testing was adopted in the experimentation. Laterite soil samples were first mixed with water and compacted using Standard Proctor compaction. The same samples were then remixed at higher water contents and recompacted. The compacted and recompacted soil samples were subjected to falling head permeability tests. Based on the tests results, the permeability value of 2.24 x 10^{-8} m/s for recompacted laterite soil at 40% moulding water content was lower than the permeability value of 5.95 x 10^{-8} m/s for compacted sample at the same moulding water content. The laterite soil was observed to contain low fines content and is susceptible to crushing.

Keywords: Permeability, Compaction, Laterite soil

INTRODUCTION
A sanitary landfill is a facility where waste is isolated from the environment. To construct an engineered sanitary landfill, the soil materials need to have permeability as low as possible to prevent leachate from passing through which can cause groundwater contamination. According to most environmental agencies, the final liner and cover system of a landfill must have permeability of ≤ 1 x 10^{-9} m/s (UKEA, 2014; DWAF, 1998; USEPA, 1993; EPA, 2000; EPA, 1996).

The measure or capacity of a fluid to flow through a porous medium (soil) is known as permeability (or hydraulic conductivity). Permeability is typically evaluated as a two-dimensional rate of flow that is critical in the design of drainage, filtering and hydraulic barriers. It is related closely with grain size and grain size distribution, and can be strongly affected by density, grain arrangement (structure), confining stresses, and other variables. Of notable interest is that the magnitude of permeability varies more than any other soil property, most often reported by including order of magnitude. Permeability is typically anything but uniform in the field due to its truly three-dimensional nature, and the resulting effects on flow prediction can be one of the most difficult soil phenomena to accurately assess (Nicholson, 2014).

Permeability is the key design parameter when evaluating the acceptability of a barrier material. Low permeability is achieved when the soil is compacted at high dry density and a water content wet of optimum (Daniel, 2012). Compaction of soil is the process by which the solid particles are packed more closely together, usually by mechanical means, thereby increasing the dry density of the soil. The dry density which can be achieved depends on the degree of compaction applied and on the amount of water present in the soil. For a given degree of compaction of a given cohesive soil there is an optimum moisture content at which the dry density obtained reaches a maximum value. Nevertheless, the method of sample preparation depends on whether the soil sample is susceptible to crushing during compaction (Head, 2006). For soils containing particles that are susceptible to crushing, it is necessary to prepare separate batches of soil at different moisture contents each for compacting once only. Otherwise the characteristics of the soil material will progressively change after each application of compaction.

The material to be compacted and tests its permeability in this research is laterite soil. Laterite is a soil rich in iron and aluminium, and is commonly considered to have formed in hot and wet tropical areas. Nearly all laterites are of rusty-red coloration, because of high iron oxide content. They develop by intensive and long-lasting weathering of the underlying parent rock. Tropical weathering (laterisation) is a prolonged process of chemical weathering which produces a wide variety in the thickness, grade, chemistry and ore mineralogy of the resulting soils (Gidigasu, 2012). Laterite is composed of both cohesionless and cohesive soils. This forms the basis of laterites being referred to as C-Ø (C-Phi) soils. The cohesionless portion consist of gravels and sands while the cohesive portion includes fines particles usually in silt and clay sizes. Laterite soils behave in a unique way by changing volume when exposed to humidity variations. Hence, some components are referred to as stable i.e. gravel and sand, while silt and clay are referred to as unstable. Stability in this sense is based on their ability to withstand variations in terms of moisture without a significant change in its properties, which is of course is fundamental in materials for building construction (Oyelami and Van Rooy, 2016).

This research investigates the effects of recompaction on permeability of laterite soil. On the other hand, it provides an insight whether the laterite soil used is susceptible to crushing when recompacted or not.

MATERIALS AND METHODS
The laterite soil sample used was extracted from the Faculty of Electrical Engineering at 1-1.5 m below the ground level in Universiti Teknologi Malaysia (UTM), Johor. All tests performed followed the British Standard (BSI, 1990) and for permeability test the Head's Manual of Soil Laboratory Testing (Head and Epps,

2011) was adopted. Compaction test and index property tests were conducted to determine the soil basic characteristics at their natural state. These tests include the particle size analysis, Atterberg limit test, and specific gravity determination.

Compaction Test

The Standard Proctor compaction procedure is listed accordingly:

1. Weight about 2.5 kg of the soil sample and pass through 4.75mm sieve to remove oversize gravel.
2. Measure the percentage of water content by dry weight of soil and mix it thoroughly.
3. Keep the mixed soil into a seal plastic bag for 24 hours.
4. After the moisture had spread evenly throughout the soil, put the soil into a tray and divide it into 3 parts equally.
5. Take the weight of the compaction mould.
6. Take one-third of the parts and compact it into the mould by dropping 27 blows using 2.5 kg rammer with a drop distance of 300 mm to make the first layer.
7. Repeat stage 6 for the second and third layers. Making sure that the blows are uniformly distributed over the surface of each layer.
8. The amount soil used should be sufficiently enough to fill the mould.
9. Remove the collar of the mould and trim the excessive soil using a straight edge.
10. Clean the mould from outside and take again its weight.
11. Take a representative sample of the soil for water content determination.
12. Calculate the internal volume of the mould.
13. Calculate the bulk density of each compacted specimen.
14. Calculate the dry density of each compacted specimen.
15. Plot the dry densities obtained against the corresponding moisture contents. Draw a curve of best fit to the plotted points and identify the position of the maximum on this curve. Read off the values of Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) corresponding to that point.
16. On the same graph, plot the curve corresponding to zero air voids.

Recompacted Laterite Soil Procedure

17. Follow step 1 until step 7 from the Standard Proctor compaction procedure.
18. After the soil had been compacted, loosen the soil and add another 5% water content.
19. Mix the soil thoroughly to make sure the moisture spread evenly throughout the soil.
20. Keep the mixed soil into a seal plastic bag for 24 hours for better spreading of the moisture content.
21. Afterwards, take out the soil and repeat step 4 until step 16 from the Standard Proctor compaction procedure.

Permeability Test

Compacted soil samples were subjected to the falling head permeability test as described below.

1. Assemble the mould and the permeameter cell. Fit a wire gauze disc to each end of the sample. Ensure that the rubber disc is in place to so that a watertight joint is made. Tighten down the wing nuts on the straining rods progressively and evenly.
2. Place the assembled cell in the immersion tank or a bucket and fill it with water up to the overflow level. Tilt the cell to release any entrapped air from underneath the cell top.
3. The immersed cell should be let saturated for at least 48 hours until all the air bubbles had escaped from the cell. If the air bubbles are no longer coming out, it means that the sample is saturated and can continue to the next step.
4. Fill the water supply tank with de-aired water. For a low permeability sample, the de-aired water should only be filled sufficiently.
5. Before the permeability test can run, the manometer tube must not have any entrapped air bubbles. Let the de-aired water to flow through the manometer tubes until all the bubbles had gone out.
6. Connect the standpipe's manometer tube with the inlet of the permeameter cell.
7. Open the screw clip from the manometer to let the water flow down through the sample and observe the water level in the stand pipe. As soon as it reaches the water level h_1, start the timer clock. Observes and record the time when it reaches h_2, then stop the clock. Close the screw clip.
8. Repeat the procedure for the standard compacted and recompacted samples. The manometer tubes may need to be refill with de-aired water.
9. Calculate the coefficient of permeability (*k*) and report the results using Equation 1.

$$k = 2.3 \frac{aL}{At} \log_{10} \frac{h_1}{h_2} \tag{1}$$

Where;
k = Coefficient of permeability (m/s)
a = Area of the standpipe (m^2)
L = Length of sample (m)
A = Cross sectional area of sample (m^2)
h_1 = Initial height of water in standpipe (m)
h_2 = Final height of water in standpipe (m)
t = Time required to get head drop (s)

RESULTS AND DISCUSSION

Index Properties

The particle size distribution test showed that the laterite soil contains gravel, sand, and fines of 36.4%, 34.9%, and 28.7% respectively. The particle size distribution curve is shown in Figure 1. Moreover, Table 1 illustrates the basic index properties of the laterite soil used. According to British Standard Classification System (BSCS), the soil can be classified as very silty gravel with sand of very high plasticity.

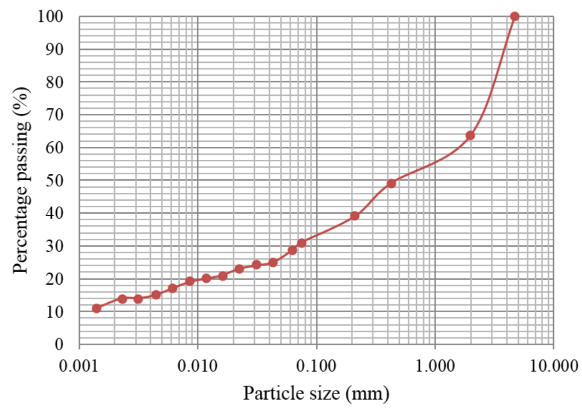

Figure 1: Particle size distribution curve of the laterite soil

Table 1: Index properties of laterite soil

Parameter	Value
Specific Gravity	2.74
Liquid Limit, %	80.29
Plastic Limit, %	41.19
Plasticity Index, %	39.1
OMC, %	31
MDD, Mg/m^3	1.38
Classification based on BSCS	MV

Compaction

Based on Figure 2, it shows that the recompacted samples had higher dry density than the standard compacted samples. This behaviour may be explained by the type of sample used. According to BS1377:1:1990, specimens which are susceptible to crushing may change its properties if compacted more than once. It means that the samples used is susceptible to crushing because when it was recompacted the maximum dry density increased from 1.38 to 1.42 Mg/m^3. When the sample was recompacted, it breaks down into finer particles enabling it to fill out the existing voids of the soil.

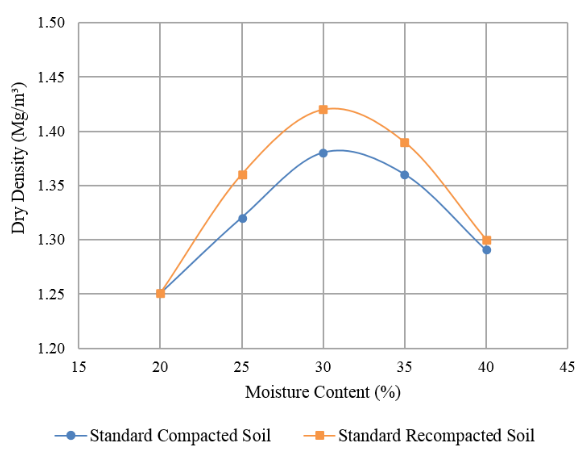

Figure 2: Compaction curves for Standard compacted and recompacted samples

Permeability

For the permeability tests of standard compacted and recompacted laterite soil, it shows that the recompacted laterite soil had lower permeability values than the compacted soil. Recompaction brings about breakdown of the soil particles into finer sizes enabling them to fill the voids that exist within the soil sample. This is in line with (Osinubi et al., 2012), that lateritic soils with large percentage of fines were observed to possess a significant pollutant retention capacity. The fines content in coarse soils are carefully considered because they determine the composition and type of soil and affect certain soil properties such as permeability, particle friction and cohesion (Adunoye, 2014). Compacted fine-grained soils are famous as buffer material for waste repositories due to their auspicious self-sealing abilities. Their swelling potential is required to fill voids and fractures, and provide low permeability to achieve an impermeable zone around the landfill (Amadi, 2013). The laterite soil used in this research contained 28.7% fines content which could be the reason why the permeability is greater than 1 x 10^{-9} m/s. For tropical laterite soils to have the required permeability of 1 x 10^{-9} m/s, a minimum fines content of 50% is recommended (Yamusa et al., 2018; Yamusa et al., 2017; Yamusa et al., 2016).

Figure 3 shows a general decrease in permeability with increase in moulding water content. The permeability for compacted sample decreased from the range of 2.23 x 10^{-6} to 5.95 x 10^{-8} m/s for 20 to 40% water content respectively. Likewise, for the recompacted sample the permeability decreased from the range of 2.23 x 10^{-6} to 2.24 x 10^{-8} m/s for 20 to 40% water content respectively. The decrease in permeability is attributed to the larger degree of dispersion in soil structure with higher moisture content. For a given compaction energy, the permeability at wet of optimum water content, is significantly lower than the permeability at dry of optimum water content (Amadi and Eberemu, 2012). Likewise, compaction with higher moulding water content result in soil grading that were devoid of macropores (i.e. pores being filled with water) which conduct flow (Osinubi et al., 2015). Additionally, soil-water interaction results to the formation of diffuse double layer. As the diffuse double layer of adsorbed water and cations expands, hydraulic conductivity decreases because flow channels become constricted (Daniel, 2012).

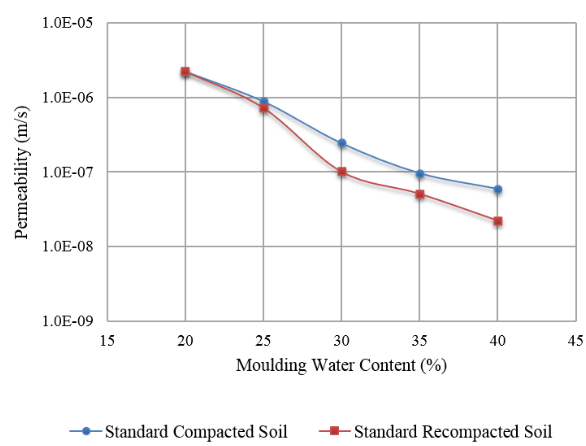

Figure 3: Permeability curves of Standard compacted and recompacted samples

Conclusion

Based on the results, the standard recompacted samples generally produced lower permeability than the standard compacted samples. The difference of permeability between those two types of samples is attaining to about one order of magnitude. The difference occurred due to susceptibility of the laterite soil particles to crushing, resulting in its rearrangement and reorientation. As the soil samples were recompacted, the crushed particles filled the void with the soils which makes the flow of water more difficult. Rearrangement and reorientation of soil particles yielded more dense samples, thus reducing the permeability. This research shows that by recompacting the laterite soil, the dry density can go higher and the permeability values become lower. According to environmental agencies and researchers, the maximum permeability value of a sanitary landfill liner is 1×10^{-9} m/s. Though the laterite soil used in this study had higher permeability value of 5.95×10^{-8} m/s and 2.24×10^{-8} m/s at 40% water contents for the compacted and recompacted samples respectively. A laterite soil with higher fines content can be used to attain the criteria, which is encouraged to be investigated.

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