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Effects of Gradation on Hydraulic Conductivity Properties of Compacted Laterite Soil Liner: A Review

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Abstract— This paper presents the recent review on the effects of gradation on hydraulic conductivity properties of compacted laterite soil liner. The distribution of different grain sizes affects the engineering properties of soil such as compressibility, shear strength, and hydraulic conductivity. It is observed that there are variations in hydraulic conductivity values in laterite soils from various researches around tropical countries of the world. Hydraulic conductivity varies from 4.36×10^{-3} m/s to 4.7×10^{-11} m/s relative to fine contents ranging from 1.3% to 69% and coarse contents ranging from 31% to 98.7%. Generally, there is no clear trend established for effects of gradation on hydraulic conductivity properties of compacted laterite soil liners. This is because laterite soils with less than 50% fines content cannot be used as liner or hydraulic barriers because their hydraulic conductivities are less than the minimum requirement of 1×10^{-9} m/s. It is anticipated that with logical understanding of the effects of gradation on hydraulic conductivity properties of compacted laterite soil it will serve as a guide in the design of hydraulic barriers for engineered sanitary landfills in tropical countries around the world.

Index Terms— Gradation, hydraulic conductivity, landfill, laterite, liner

1 Introduction

One of the major problems facing urban communities today is the efficient and long term disposal of waste. For instance, in Malaysia, the increasing population and industrial activities result in more waste generation annually. Landfills are being filled up rapidly due to the current daily generation of approximately 30,000 tonnes of municipal solid waste (1). Demand of common landfill liner materials will significantly increase due to construction of larger capacity landfills sites. When demand is more than supply, the cost of the material will certainly rise. With regard to this, it is clear that provision of material for liner construction is becoming less economical, because these materials are composed of clayey or mixed (with Bentonite) soils due to their low hydraulic conductivity (2). In addition, these materials may not be locally available and may have to be imported from somewhere else, and could significantly increase the cost of construction. Therefore, it is very essential to search for local materials available for the construction of compacted soil liners. For a project to be viable, the materials to be used have to be relatively abundant. Thus, laterite soil which is commonly available is investigated. Likewise, much of the current practices in conventional geotechnical engineering have relied mainly on experience with soils from temperate regions.

However, laterite soils are different in various characteristics that lead to differences in general properties and behaviour. This research explores the effects of gradation on hydraulic conductivity properties of compacted laterite soil to be used in the design of sanitary landfill liner.

2 Laterite Soils

Laterite is a residual of rock decay that is reddish in colour and has a high content of iron oxides, hydroxides of aluminium and low proportion of silica. These soils are pedogenic materials, the formation of which requires conditions of temperature and rainfall that characterize the humid tropical and subtropical zones of the world (3). Laterites occur in six main regions of the world which are Africa, Australasia, Central and South America, India, Southeast Asia. Lateritic materials constitute the major surfacial deposit of engineering materials in many parts of tropical regions (4). Lateritic soils are residually formed from a variety of parent rocks. All laterite soils possess a permanent feature of high content of iron, aluminum, or titanium oxides in relation to other constituents (3).

They are formed under weathering systems productive of the process of laterization, the important characteristics of which is the decomposition of ferro-alumino silicate minerals and the permanent deposition of sesquioxides within the profile to form the horizon of material known as laterite (3). They occur mostly as the toppings of soil and therefore provide excellent borrow spaces for wide use in several construction activities.

According to (5), the geotechnical characteristics and field performance of laterites are influenced considerably by their pe-

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dogenesis, degree of weathering, morphological characteristics, chemical and mineral compositions as well as prevailing environmental conditions. They categorized lateritic weathering profile derived from granite basement into three major horizons below the humus stained top soil: (i) the sesquioxide rich lateritic horizon with sometimes gravelly or hardened insitu as crust, (ii) the mottled zone with evidence of enrichment of sesquioxide sand and (iii) the pallid or leached zone which overlies the parent rock and contain rocks suffering from chemical and mineralogical changes, but retaining their physical appearance.

3 Gradation Of Compacted Laterite Soil Meant For Liner

3.1 Percentage Fines

The traditional selection and performance criteria for assessing the technical suitability of materials meant for hydraulic barriers in waste disposal facilities are low hydraulic conductivity, adequate shear strength and low volumetric shrinkage (4, 6-8). These criteria in most regulatory agencies (guidelines) and researches specified a minimum of 20% fines with respect to gradation. A minimum of 200 kN/m^2 shear strength, maximum hydraulic conductivity of 1×10^{-9} m/s and less than or equal to 4% volumetric shrinkage are required for hydraulic barrier systems. But these guidelines seem to be different from laterite soil with respect to the gradation of 20% fines content. Other researchers like (4, 6, 9) also investigate the geotechnical properties of laterite soil as liner material.

In the following, the effects of gradation on hydraulic conductivity properties of compacted laterite soil for engineered sanitary landfill liner are compared with those from studies in the literatures and discussed.

3.2 Hydraulic Conductivity

Hydraulic conductivity which refers to the degree of ease with which a fluid can flow through a material should have a maximum value of 1×10^{-9} m/s for engineered sanitary landfill liners (10, 11). Hydraulic conductivity is the major factor affecting the performance of hydraulic barriers (2). Soils with high permeability are considered undesirable for landfills. The infiltration of water through this soil is high and the possibility of groundwater pollution may increase. To protect the groundwater, it is preferable that the soil content is clayey that has very low permeability (12).

A few numbers of experimental studies dealing with the gradation effects on hydraulic conductivity of laterite soil are available in the literatures. Studies by numerous investigators (13-15) indicate that hydraulic conductivity of compacted natural soils depend on soil composition such as particle size distribution, soil structure as determined by moulding water content and compactive effort, among other factors. Moreover, current recommendations for construction quality control of soil liners suggest that soft data (plasticity index, clay content, gravel content, water content, and dry unit weight) be used as the primary means to control construction. Trial sections or test pads should be used prior to construction to verify that construction methods to be used yield acceptably low hydraulic conductivity at field scale (16). The particle-size distribution of compacted clay affects hydraulic conductivity because the size of voids conducting flow is affected by the relative proportions of large and small particle sizes. Low hydraulic conductivity is likely to be achieved when the soil is well graded and the clay fraction governs the hydraulic behavior of the matrix (16). The fines in a soil have a higher impermeabilizing effect if they are well distributed so they can most effectively plug voids among the larger particles. Mechanical mixing distributes fines and breaks down some of the soil aggregates thereby supplying fines for void-plugging and destroying large voids (14).

(17) presents the effect of particle size distribution on hydraulic conductivity of three compacted reddish brown tropical soils from Nigeria. The hydraulic conductivities for specimens with fines content of 66.4% were more sensitive to moulding water content for all compactive efforts than the remaining specimens with lower fine contents. According to (14), grading modulus can be used to explain the changes observed. The grading modulus captures the fines to medium sand fraction of the soils which contribute to changes in hydraulic conductivity especially on the wet side of the optimum water content. However, hydraulic conductivities of all the specimens at energy level of Reduced Proctor compaction effort are generally higher than 1×10^{-7} cm/s. By this, it can be understood that compaction of reddish brown tropical soils in the field using compaction energies equivalent to that of the Reduced Proctor will produce unacceptable hydraulic conductivity values for liners. Compaction of soil samples at the energy of Standard Proctor used on his study gave hydraulic conductivity values that were lower than 1×10^{-7} cm/s.

Osinubi and Nwaiwu (18) describe research on three lateritic soil samples with differences in fines contents that ranged from 64 to 72%. The values of hydraulic conductivity for the soils decreased with higher molding water contents and compactive efforts. Soil sample specimens with the lowest grading modulus value of 0.45 had hydraulic conductivity values that were less than 1×10^{-9} m/s to a greater extent than did specimens of soil samples with higher grading modulus, at molding water contents ranging from 12.5 to 22.5%.

(19) performed a study on a well graded lateritic soil. The lateritic soils contained 60% – 65% fines, 2% - 3% gravel and 31% to 38% sand. Coefficient of permeability was observed to reduce with higher compaction energy. This may be attributed

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to the reduction in the pores as compaction energy increases, and this removes or reduces the large pores through which fluid flows. The soils can be classified as practically impermeable soils based on the permeability values (19).

From this review it was found that laterite soils with less than 50% fines content cannot be used as liner or hydraulic barriers because their hydraulic conductivities are less than the minimum requirement of 1×10^{-9} m/s (see Table1). Therefore, laterite soil can said to be only used when it contains more than 50% fines, because that is when it satisfies the criteria or guideline of liner design. But this contradicts the minimum 20% fines content specifies by USEPA. Hence, an investigation into the gradation aspect of tropical laterite soil is paramount in the design of liners or hydraulic barriers for sanitary landfills.

Table 1. Percentage grain sizes of compacted laterite soil with respect to hydraulic conductivity

Author	Gravel (%)	Sand (%)	Fines (%)	Hydraulic Conductivity (m/s)	Country
(19)	3	32	65	4.75×10^{-9}	Nigeria
(20)	0	54	46	2.06×10^{-8}	Nigeria
(21)	31	12	57	7.91×10^{-9}	Nigeria
(5)	-	63	37	4.36×10^{-3}	Nigeria
(22)	16.8	81.9	1.3	2.06×10^{-7}	India
(23)	0	33	67	4.7×10^{-11}	Ghana
(24)	2.98	40.31	56.71	3.93×10^{-10}	Nigeria
(25)	0	34	66	1.9×10^{-10}	Malaysia
(26)	0	76	24	1.0×10^{-7}	China
(27)	0	31	69	1.3×10^{-9}	Brazil

4 Conclusion

Generally, there is no clear trend established for effects of gradation on hydraulic conductivity of compacted laterite soil. The effects of gradation on hydraulic conductivity properties of compacted laterite soil liner can be explained by mixing different percentage of grain sizes of fine and coarse contents of laterite soil. Therefore, the optimum ratios that satisfy the liner design criteria in order to provide guidance to geotechnical engineers in selection of this material for construction needs to be determined.

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