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A Review on the Fundamental Engineering Properties of Compacted Laterite Soil at Different Gradations

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Yamusa Bello Yamus[1,2], Ahmad Safuan A. Rashid[1], Kamarudin Ahmad[1,*], Norhan Abd Rahman[1]

[1] Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia
[2] Department of Civil Engineering, Nuhu Bamalli Polytechnic, 810001 Zaria, Nigeria

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ABSTRACT

Laterite soils are occasionally associated with geotechnical problems such as road deformation, erosion, settlement, dam seepage, slope instability, leachate permeation through hydraulic barriers, etc. Numerous soil improvement techniques were being applied to overcome these problems, including mixing the laterite soil with cements, limes, bitumen, chemicals, pozzolanas, etc. These additives may not be locally available and cheap, and could significantly increase the cost of construction. Likewise, in many cases, these stabilizing agents are not environmentally friendly. Different percentages of fines, sand and gravel in laterite soils exhibit different engineering characteristics and behaviour, making it difficult to obtain suitable and appropriate gradation for specific construction purposes. Thus, the essence of this review is to determine the fundamental engineering properties of laterite soil as a standalone material at different gradations to harness its potentiality for various construction purposes. It proposes step-by-step procedures on how to achieve a better soil by varying its gradation and moisture content. Laboratory testing in accordance with BS1377:1990 and ASTM D698 are adopted to examine the engineering characteristics with respect to hydraulic conductivity, shear strength, and volumetric shrinkage. In this experimental technique where molding water content and compaction energy are carefully controlled at different laterite gradations, the engineering design is anticipated to provide greater accuracy, safety, and sustainability.

1. Introduction

Selection of appropriate method to improve laterite soils to be used in construction projects is essential to geotechnical engineers. The use of laterite soils as material for many construction projects are sometimes limited by the difficulty in handling them. Some laterite soils consist of high plasticity clay, which may cause cracks and damage on building foundations, pavements, highways or other structural construction projects when dry [1]. Attempts to improve their workability with modifying/stabilizing agents have shown promising results. However, the application of such modifiers/stabilizers may be associated with environmental hazards, i.e., danger of release of heavy metal leachates to the aquifer [2]. It is therefore important to understand the behaviours and

* *Corresponding author.*
E-mail address: kamarudin@utm.my (Kamarudin Ahmad)

properties of laterite soils and thus figure out a suitable method to overcome their challenges. Fundamentally, compaction to increase soil strength and loading capacity as well as to decrease settlement, shrinkage and hydraulic conductivity of laterite soil at different gradations seems to be a better environmental and economical choice [3].

2. Laterite Soils

Chemical and physical weathering of parent rocks formed materials known as residual soils. These weathering processes also produce different types of clay minerals and structural arrangements. Mineralogy and structures play important roles on residual soils by providing the base for classifying residual soils into groups that are expected to have similar engineering properties.

The term laterite refers to soil deposits in which weathering has extensively occurred resulted in a concentration of iron and aluminium oxides (the sesquioxides gibbsite and goethite), which act as cementing agents. Laterite soils are used for road subbases or bases and other engineering applications [4]. A soil whose ratio of iron to aluminum oxides is less than 1.33 is termed laterite soil, whereas a lateritic soil has a ratio between 1.33 and 2.00 [5]. Laterite soils are rich in free iron oxides. The free iron oxides have discrete electrochemical properties, moderately high surface energy, an ability to adsorb substances, and offer basic cementation in the soil. Thus, free iron oxides influence the soil properties [6].

3. Physical Indices and Engineering Properties

Engineers extensively categorize various kinds of soils into wide-ranging groups, namely gravel, sand and fines. These groups are further characterized into sub-groups based on their physical indices and engineering properties. Classification tests to determine indices and engineering properties provide the engineers with valuable information on soil characteristics when the results are compared against empirical data [7].

According to Maail *et al.*, [7] and Head and Epps [8]; Index Properties: The principle indices used in geotechnical engineering include plastic limit, liquid limit, shrinkage limit and particle size distribution.

Engineering Properties: The principle engineering properties used in geotechnical engineering are shear strength, compressibility, consolidation and settlement, and permeability of the soil.
In this review, engineering properties with respect to hydraulic conductivity, shear strength and volumetric shrinkage are considered.

4. Gradation

Different percentages of fines, sand and gravel in laterite soils show different engineering characteristics and behaviours, making it difficult to obtain suitable and appropriate gradation of laterite soil for specific construction purposes. Moreover, some laterite soils may consist of expansive clay minerals which tend to cause volume changes due to changes in moisture contents leading to cracks and damage on building foundations, pavements, highways or any other construction projects.

Meanwhile, some laterite soils may consist too much of coarse particles which can cause seepage through dams and hydraulic barriers. Attempts to improve their workability and engineering properties with modifying/stabilizing agents has shown promising results, although might be accompanied by risk of release of hazardous substances from the stabilizing agents to the groundwater. It is therefore important to understand the properties and behaviors of laterite soils and thus figure out a suitable method to overcome their challenges.

Soil gradation is an indicator of engineering properties such as compressibility, consolidation, swelling and shrinkage, hydraulic conductivity, and shear strength [9]. The distribution of diverse grain sizes disturbs the engineering characteristics of soils which in turn influences their usability in construction works [10]. The objective of particle size distribution is to group these particles into distinct varieties of sizes, and so examine the relation amounts, by mass, of each size variety [11]. Accordingly, the possible particle arrangements and stabilities of these arrangements are many. Therefore, any single soil can exist in many different states, each of which can be viewed as a somewhat different material [12].

Tropical residual soils grain sizes range from discrete to compound grains and to large stones [13]. The engineering performances of lateritic soils are shown to be controlled by clay sized particles. The mode of formation and mineralogical composition of parent rocks in evaluating properties peculiar to clay sized particles are yet to be a subject of serious research [14]. So, it is paramount to determine the soil minerology in order to identify the elements present and also the sizes, shapes, orientations and aggregation of the soil particles.

According to Indrawan *et al.*, [15] fine grained soils are commonly mixed to reduce their possibility of shrinkage and swelling. Additives such as cement, lime, bitumen, fly ash, pozzolana and slag have shown to suitably reduced volume change [16-23]. The additions of additives not only reduce shrink–swell behaviour but also modify other soil properties like shear strength and permeability [1,3,24-27]. Even though chemical additives are widely used, the long-term stability of the soil mixtures is still open to questions.

An alternative method of soil improvement is by mixing fines with coarse grained soils. The effects of coarse grained soils particularly gravel on soil properties like dry density, void ratio, permeability and shrink–swell potential of soils were investigated by numerous researchers [15, 28-30]. However, the effects of coarse grained materials on the properties of residual soils under saturated and unsaturated conditions remain unclear [15]. Addition of gravelly sand to a residual soil can lower shrinkage potential of soil material used as soil barrier. Meanwhile, in order to obtain a moderately high permeability and low shrinkage potential residual soil, medium sand can be added for use as subgrades of roads and pavements.

The maximum amount of gravel that should be allowed in the soil barrier material depends on the steps taken to ensure that the gravel is uniformly mixed with the soil and is not segregated from the soil. Because construction techniques are highly variable, the maximum amount of gravel that should be allowed in soil barrier materials may likewise be variable [28].

The construction industry is experiencing rapid increase development. To have sufficient information and knowledge about the numerous methods of improving soils to be used in several construction projects is of crucial concern to geotechnical engineers. It is also economically viable to increase the soil resistance, strength, permeability, as well as to limit water absorption, control soil erosion, losing water, and soil settlement [31].

Considering the limited information on laterite soil gradation as stipulated by Yamusa *et al.*, [32,33], this research aims to provide an insight on sustainable design method in the use of laterite soil as a stand-alone material when its gradation is considered in engineering constructions. The focus is on developing the idea on laterite soil gradation to address the engineering properties limitations to enhance sustainability for the benefit of future designs. Therefore, it is expected that by varying the gradation of laterite soil, it can provide some suitable ranges of various results. Then from these results an optimum value can be extracted which can be applied to relevant problem in the construction field.

5. Methodology

All experimental works are to be carried out in accordance to the standard of practices. In this study procedures outlined in the British Standard (BS), [34] are to be used. However, in some cases where the experimental procedures are not covered in this standard, the American Society for Testing and Materials (ASTM) [35] standard is adopted. Similarly, procedures followed in similar research topics are also to be adopted with or without modifications where necessary. To ensure the reliability and reproducibility of results, calibrations of equipment and replication of tests are to be carried out in the experiments. Figure 1 shows the flow chart of the proposed research methodology, on which the explanation hereafter is based.

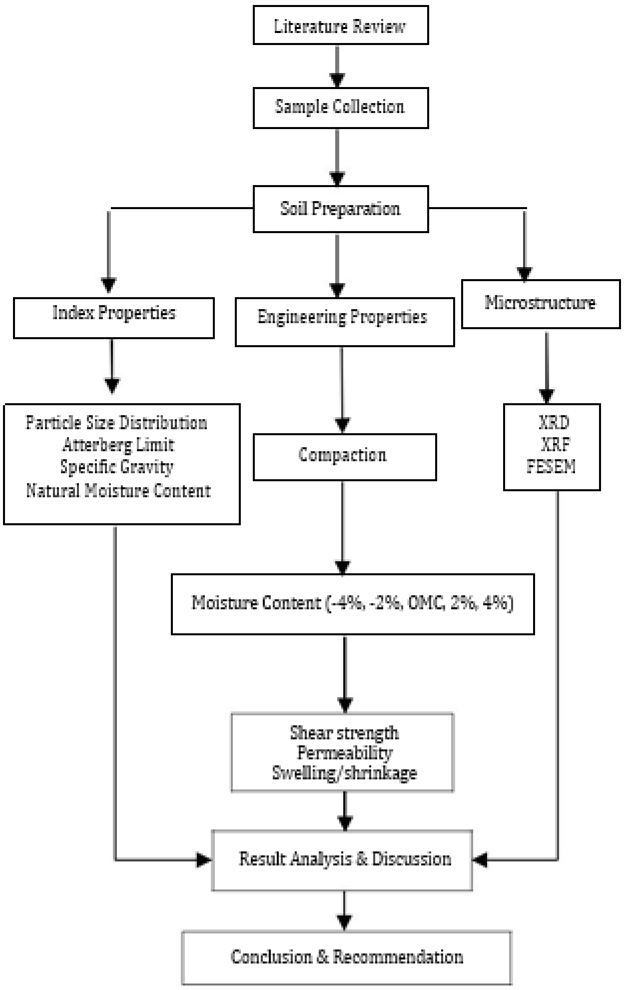

Fig. 1. Proposed research flow chart

5.1 Material

Laterite soils will be collected from burrow pits on site at a depth of about 1.0 m below the natural ground surface. This is to avoid the dense organic matter contents present at surface. Then, it will be taken to the geotechnical laboratory for experiment. The soil sample should be air dried and sieved into different grades, i.e. fines (<0.063 mm), sand (0.063 mm to 2.00 mm) and gravel (>2.00 mm to 4.75 mm). These different grades will be mixed to give reconstituted samples.

Laterite soil gradations to be tested can take the following formats:
Natural laterite soil with 30% fines, 40% sand and 30% gravel.
Reconstituted laterite soils:
Laterite soil mixtures of 40% fines, 40% sand and 20% gravel.
Laterite soil mixtures of 50% fines, 40% sand and 10% gravel.

5.2 Methods

Laboratory tests to measure the engineering properties include shear strength, hydraulic conductivity and volumetric shrinkage on compacted soil samples. British Standard light equivalent to the Standard Proctor compaction tests will be performed in accordance with the procedures outlined in BS 1377: Part 4: 1990 to obtain relationship between the dry densities and the moisture contents of the soils. After the completion of the compaction tests, the maximum dry density (MDD) and the optimum moisture content (OMC) for each soil gradation will be established. Subsequently, five different moisture contents (i.e. -4%, -2%, 0%, +2%, +4% of OMC) will be added to each soil gradation and compacted for engineering properties determination.

Hydraulic conductivity tests will be conducted using falling head permeameter as recommended by [8]. The steps to be carried out with respect to laterite soil in its natural gradation are as follows:
i) 3 samples of laterite soil with the moisture content equivalents to the OMC will be compacted after which the compacted samples will be subjected to permeability tests.
ii) Procedures in step (i) are to be repeated with moisture contents -4%, -2%, +4% and +2% of OMC.

The average permeability of the samples compacted at each moisture content will be calculated and discussed. Procedures (i) to (ii) are to be undertaken on other laterite soil gradations. The hydraulic conductivity procedures are in accordance with the following researchers [36-38].

Volumetric shrinkage determination follows similar research adopted by researchers like Eberemu, Osinubi *et al*., Bello, Daniel *et al*., [22,23, 39-41]. The volumetric shrinkage upon drying will be measured by extruding the compacted cylindrical specimens. The extruded samples will be placed on a laboratory bench in a uniformly constant temperature of say 26 ± 2ºC for 30 days to dry naturally. Vernier caliper accurate to 0.05 mm will be used to take daily measurements of the diameter and height of each sample. The volumetric shrinkage strain will be computed using the average diameters and heights.

The procedures to be carried out with respect to laterite soil in its natural gradation are as follows:

i) 3 samples of laterite soil with the moisture content equivalents to the OMC will be compacted after which the compacted samples will be extruded and subjected to volumetric shrinkage testing.
ii) Procedures in step (i) will be repeated with moisture contents -4%, -2%, +4% and +2% of OMC.

The average volumetric shrinkage of the samples compacted at each moisture content will be calculated and discussed. Similar procedures from (i) to (ii) will be undertaken on other laterite soil gradations.

Unconfined compressive strength test will be conducted according to BS 1377: Part 7: 1990. Axial compression is to be applied to the soil specimen at a constant rate of deformation. Researchers like [42-44] used this method. The steps to be carried out with respect to laterite soil in its natural gradation are as follows:
i) 3 samples of laterite soil with the moisture content equivalents to the OMC will be compacted after which the compacted samples will be subjected to unconfined compressive strength tests.

ii) Procedures in step (i) will be repeated with moisture contents-4%, -2%, +4% and +2% of OMC.

The average unconfined compressive strength of the samples compacted at each moisture content will be calculated and discussed. Similar procedures from (i) to (ii) are to be undertaken on other laterite soil gradations.

Micro Structural Characterizations which include analysis using X-ray diffraction (XRD), X-ray fluorescence (XRF) and field emission scanning electron microscope (FESEM) will be performed to study the soil structural fabric and its mineralogy. An insight of the dominant clay minerals will be obtained. This helps to understand certain behavioural phenomenon that the laterite soil exhibits.

6. A Review on the Proposed Method

Soil is usually placed as fill in construction, but it is necessary to compact it in order to achieve satisfactory engineering properties that would not be achieved when in loose state. Compaction test was first introduced by Proctor in the USA in 1933 known as Standard Proctor compaction test [11]. This is similar to the test now known as British Standard light compaction test. Environmental changes caused due to moisture tends to reduce the sensitivity of strength and volume change calls for the reason of compaction test [45].

Materials for waste containments are usually investigated for some number of parameters which are considered to be relevant to their proper functioning under service condition. The design parameters to be investigated are hydraulic conductivity, volumetric shrinkage and unconfined compressive strength of the soil [39]. Likewise, these design parameters had been adopted by many researchers [19, 46-50].

Hydraulic conductivity of soil material should have a maximum value of 1 × 10-9 m/s for hydraulic barriers [39, 51-53]. Hydraulic conductivity is the major factor affecting the performance of hydraulic barriers [54]. Soils with high permeability are considered undesirable for landfills. The infiltration of water through this soil is high which can cause groundwater pollution. It is desirable to use clayey soil that has very low permeability in order to protect the groundwater [55]. Soils that are relatively more plastic and have larger quantity of fines yield lower hydraulic conductivity when compacted wet of optimums [46,56,57]. Considering compaction on wet side of optimum and high fines content, this can lead to a higher volumetric shrinkage upon drying. Therefore, the range of quantity of fines need to be determined with corresponding coarse contents.

The outcome of researches established that more than 4% volumetric shrinkage strain is required to cause substantial cracking in soil barrier [40]. Thus, the designer must ensure good control over ranges of water contents of the compacted soils to comply with the requirement specified by most regulators. Field studies have shown that compacted soil barriers (covers) undergo changes in water content due to seasonal differences even at substantial depth, as a result of evapotranspiration and precipitation [23,58]. Although low hydraulic conductivity values are obtained from soils with high fines contents, care must be taken to ensure lateritic soils with fines content greater than 70% are not used as liners or as covers because of their tendency to undergo high volumetric shrinkage [58]. [40] explains that it is likely to compact clayey sand to a low hydraulic conductivity and concurrently gets a compacted soil with negligible potential to shrink and crack when desiccated. Therefore, laterite soils with significant amount of sand can yield low potentiality for shrinkage. Likewise, a low volumetric shrinkage can be attained when the soil is compacted dry of optimum moisture content.

Compacted soils for hydraulic barriers in waste containment facilities must have adequate strength to carry its self-weight and the weight of the solid waste. The required minimum strength of soil to be used in compacted soil liners is not specified, however Daniel *et al*., [40] arbitrarily selected a minimum unconfined compressive strength of 200 kN/m2. Such strength is considered sufficiently durable in satisfying the stresses resulting from alternate wet and dry cycles [44]. The shear strength of compacted clayey soils depends on the density as well as water content. As compaction on the wet side of optimums yield lower hydraulic conductivity, care must be taken not to cause reduction in the shear strength. Literature has shown that the shear strength of laterite soil decreases with increasing molding water content [48,59]. It means that by compacting laterite soil on the dry side of optimum, a greater shear strength would be achieved.

Moreover, compaction characteristics can be affected by soil gradation coupled with plasticity of the fines. Likewise, compactive effort and moisture content can also affect the compaction characteristics. Varying each of these variables influences permeability, volume change, strength and stress-strain characteristics of the material [45]. In this review, engineering properties with respect to hydraulic conductivity, shear strength and volumetric shrinkage were considered with respect to variation in gradation of laterite soil at different moisture content.

7. Conclusions

This study reviews the engineering properties of laterite soil which can be improved by varying its gradation at different moisture contents using compaction method. The core objective of research like this one is to create limits to known settings of uniform mixing of materials. The water content of the laterite soil is varied on the wet and dry sides of optimum to indicate suitable moisture conditions during compaction. Therefore, it is expected that by varying the gradation of laterite soil, it can provide some suitable ranges of results in terms of molding moisture content. Then from these results an optimum value of optimum moisture content can be extracted which can be applied to relevant engineering problem. By varying the laterite soils gradation coupled with controlled molding water contents and compaction energy, the engineering design will be unconventional with anticipation of greater accuracy and safety. Likewise, it should be stated that this study takes a new approach as a sustainable option in the geotechnical engineering studies, especially for laterite soils in the tropical regions of the world.

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