The Use of Standard Proctor for the Determination of Shrinkage Properties of Reddish Brown Tropical Soil

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Abstract

In developing countries groundwater is used for drinking and other beneficial purposes. However, its purity and quality is compromised because of the way waste is disposed. Laboratory induced volumetric shrinkage tests were carried out on three tropical reddish brown soils (labeled MP1 – MP3) obtained from Maniya, Ibadan, south-western Nigeria to determine their suitability as liners and covers in waste containment structures. The samples prepared at - 2, 0, 2 and 4% of optimum moisture content and compacted using standard Proctor energy. Results of the study showed that volumetric shrinkage strain values increased with higher moulding water content. Only specimens prepared at 2% dry of optimum and at optimum moisture contents met the regulatory maximum volumetric shrinkage value of 4% at 18.5, 16.3 and 15.3% of the moulding water content for MP1, MP2 and MP3, respectively. Consequently, the tropical soil samples can be used in waste containment applications.

Keywords

Compaction; Containment facilities; Groundwater; Standard Proctor.

Introduction

In line with the new Millennium Development Goals (MDG), the Federal Government of Nigeria adopted a National Water and Sanitation Policy in January, 2000. According to this policy, access to potable water supply is to be increased from coverage of 4 to 60% in 2003, 80% in 2007 and 100% in 2011. Water is one of the basic necessities of life and its provision is essential for the well being of man. It has been established that the progress of sanitation throughout the world has been closely associated with the availability of water.

It was argued [1] that improvement in water supply alone will have little effect on health if sewage is still accumulating in and around the home. Thus, currently in developing countries, particularly in Nigeria, there is no cost-effective technology for the reuse and recycling of municipal solid waste (MSW).

One of the major problems presented by waste disposal facilities is the formation of leachates that are drained from the facility into groundwater [2]. Leachate originating from municipal refuse contains appreciable amounts of contaminants that may endanger public health and the environment if allowed to percolate into groundwater without protective measures to limit and control its migration. This has been a challenging task for geo-environmental engineers in recent years. Since, most people in developing countries depend on groundwater for drinking and agricultural purposes [3, 4], there is need to protect its purity. Therefore, there is need to assess whether the reddish brown soils proposed for liners and covers are suitable for use.

Potential for desiccation alongside hydraulic conductivity and shear strength among other factors are usually considered when evaluating the suitability of clayey soils to be used as compacted soil liners and cover [5]. In order to achieve hydraulic conductivities less than or equal to regulatory maximum of 1×10^{-7}cm/s, fine-grained soils used as landfills liners and covers are required to be compacted on the wet side of the line of optimums. Thus, at relatively arid sites or sites where the clay could be subjected to seasonal drying this practice could be counterproductive if the liner will eventually desiccate [6, 7]. Shrinkage and/or cracking may accompany the desiccation of compacted clayey soils depending on the water content of the compacted soil samples [8-11]. This is so because as the moulding water content of a compacted soil is increased, the shrinkage potential of the soil also increases.

The total amount of shrinkage of compacted soil depends upon the proportion of clay, type of clay mineral, exchangeable cations, orientation of clay particles, and degree of aggregation of soil [12, 13]. Total shrinkage increases with higher initial water content. This is a function of percent clay in the soil, the kind of minerals, the mode of geological deposition, the depositional environment, which determines both particle arrangement and

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overburden pressure, and the degree of weathering. Thus, the volumetric shrinkage of compacted soils occurs as a result of post-compaction moisture changes. Excessive shrinkage leads to cracks in such soils. Large cracks can occur in wet, compacted clays that are allowed to dry [14].

Compacting a soil or remoulding it changes its natural particle orientation; shrinkage being less for random than for parallel particle arrangement. Sand and silt-size particles reduce total shrinkage because they dilute the clay and decrease the volume of water held by the soil [15]. The use of clayey sands for liners and covers has been advocated [6] as they combine the attributes of low hydraulic conductivity and low compressibility to minimize the amount of shrinkage that takes place upon drying.

It pertinent to note that shrinkage cracks can occur locally when the capillary pressures exceed the cohesion or the tensile strength of the soil [6]. Cracks cause rapid infiltration of water and other fluids into the soils and for impermeable soils such as compacted clayey soils, hydraulic conductivity is increased. It has been shown that desiccation cracks formed in a hydraulic barrier soil resulted in preferential flow paths thus increasing the overall hydraulic conductivity of the soil. Segments of this soil having more cracks produced higher hydraulic conductivity.

One of the measures outlined to address the problem of induced volumetric shrinkage of low hydraulic conductivity compacted soil liners is the use of soils rich in sand that combine the attributes of low conductivity and low desiccation upon drying [16, 17, 18]. The amount of volumetric shrinkage strain depends on the structure and strength of the soil [19]. Most of the published data are on temperate zone soils, particularly from North America and Europe [20, 21, 22]. Temperate zone soils are different from tropical soils [23].

Thus, the aim of this study was to investigate the effect of soil type and moulding water content on shrinkage characteristics of three compacted tropical reddish brown soils from Ibadan, south-western Nigeria when used in waste containment application.

Materials and Methods

The method of disturbed sampling was employed in obtaining soil samples for laboratory testing. The soil samples designated as MP1, MP2 and MP3 were obtained at depths of 0.80 – 2.90m from Moniya, Akinyele Local Government, Ibadan (latitude 7°27' and longitude 4°59'). The soils are classified as A-7-6 according to the Association of American States Highway and Transportation Officials Classification System [24] and lean clay with sand (CL), according to the Unified Soil Classification System [25]. The specific gravities of the soils are in the range 2.62- 2.66, while their pH is in the range 6.10 - 6.20. The percent passing BS No. 200 sieve are in the range 59.2 - 66.4%.

Index properties

Laboratory tests were carried out to determine the index properties of the soil samples in accordance with British Standard [25].

Compaction

The specimens were prepared by mixing the relevant quantity of dry soil samples previously crushed to pass through BS No.4 sieve (4.76 mm aperture) as outlined in BS 1377 [25] and ASTM [24]. The specimens were prepared using moulding water content in the range 5.9 - 22.4%. The compaction method used is the standard Proctor which is easily achieved in the field.

Volumetric shrinkage

The volumetric shrinkage upon drying was determined using compacted cylindrical specimens. Specimens were compacted using the standard Proctor energy at optimum moisture content, two and four percents dry and wet of the optimum moulding water content. The specimens were carefully extruded from the 1000 cm^3 moulds and left on a table to dry at room temperature of 25 ± 2°C (see Figure 1). This temperature range has minimal rate of evaporation with no shrinkage forces that could induce cracking. The weights and dimensions of the specimens were measured regularly for 30 days until no changes in the dimensions and weights were observed. Three measurements of diameter and height, respectively, for each specimen were taken every 5 days with the aid of a vernier caliper accurate to 0.05 mm. The average diameters and heights were used to compute the volumetric shrinkage strain.

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Figure 1. *Tropical reddish-brown soil specimens on the drying table*

Results and Discussion

Index properties

The results of the index properties and compaction characteristic of the soil samples are summarized in Table 1, while the particle size distribution curves are shown in Figure 2. The clay mineralogy of the soil samples which was quantitatively analyzed using x-ray diffraction (XRD) was determined to be kaolinite. The soil samples have activity values less than 1. The higher the activity of a soil the greater the clay fraction influences its properties. The chemical composition of the soils is summarized in Table 2.

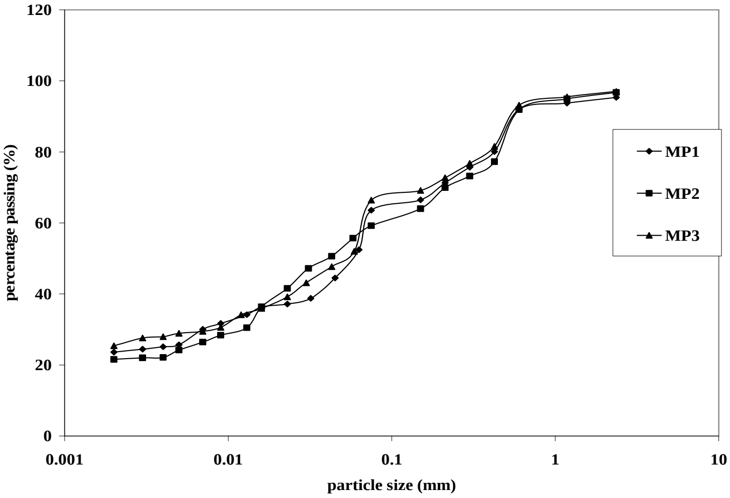

Figure 2. *Particle size distribution curves for the three reddish-brown tropical soils*

Table 1. Index properties of reddish-brown soils

Properties	**Soil Samples**		
	MP1	**MP2**	**MP3**
Natural moisture content, %	5.2	5.9	5.6
Specific gravity	2.66	2.62	2.65
Liquid limit, %	43	48	44
Plastic limit, %	29	32	28
Plasticity index, %	14	16	16
Linear shrinkage, %	8.60	7.80	6.25
% Passing BS No. 40 sieve	80.1	77.25	81.55
% Passing BS No. 200 sieve	63.55	59.2	66.4
% < 2 μm	23.63	21.57	25.39
Maximum dry unit weight, kN/m^3	17.46	17.46	17.85
Optimum moisture content, %	17.8	15.4	15.1
AASHTO classification	A-7-6(8)	A-7-6(9)	A-7-6(8)
USCS	CL	CL	CL
Activity	0.55	0.68	0.74
Derived Parameters			
Grading modulus	0.61	0.67	0.60
Plasticity product	889.7	947.2	982.4
Plasticity modulus	1121.4	1236.0	1304.8

Table 2. Chemical composition of soil samples

Oxides	**Concentration, %**		
	MP1	**MP2**	**MP3**
Fe_2O_3	9.2	7.7	8.2
CaO	4.3	4.1	7.2
MnO_3	0.31	0.10	0.35
K_2O	1.0	0.6	1.6
Cr_2O_3	0.12	0.13	0.3
Al_2O_3	5.1	3.3	4.1
SiO_2	3.4	5.7	2.2
Organic Carbon	0.05	0.07	0.02
pH	6.10	6.20	6.20
EC μmhos/cm	0.29	0.26	0.16

The concentrations of Fe_2O_3 are in the ranges 8.2 - 9.2% for the soil sample in agreement with [18]. It can be stated that as ferruginous soils, they contain free iron oxides which have been transformed to the active forms [17, 22].

Influence of Moulding Water Content on Shrinkage

The variation of volumetric shrinkage strain with moulding water content is shown in

Figure 3. As can be seen in these figure, volumetric shrinkage strain increased as the moulding water content increased. Volumetric shrinkage strains of 6.2, 6.5 and 6.6% for soil samples MP1, MP2 and MP3 were recorded at moulding water contents of 21.8, 19.4 and 19.1%, respectively. Maximum acceptable volumetric shrinkage strain value of 4% was attained at 18.5, 16.3 and 15.3% of the moulding water content for MP1, MP2 and MP3, respectively. Soil sample MP3 which has highest fines content and lowest grading modulus (see Table 1) shrunk most particularly at higher moulding water content which is in line with the findings of [9] who reported that volumetric shrinkage strain increased with higher clay content. Volumetric shrinkage strain increased because soils with higher clay content or plasticity index have a greater affinity for water. Volumetric shrinkage strain (VSS) increased within a narrow range (i.e., 11.1 – 19.1%) of moulding water content (see Figure 3).

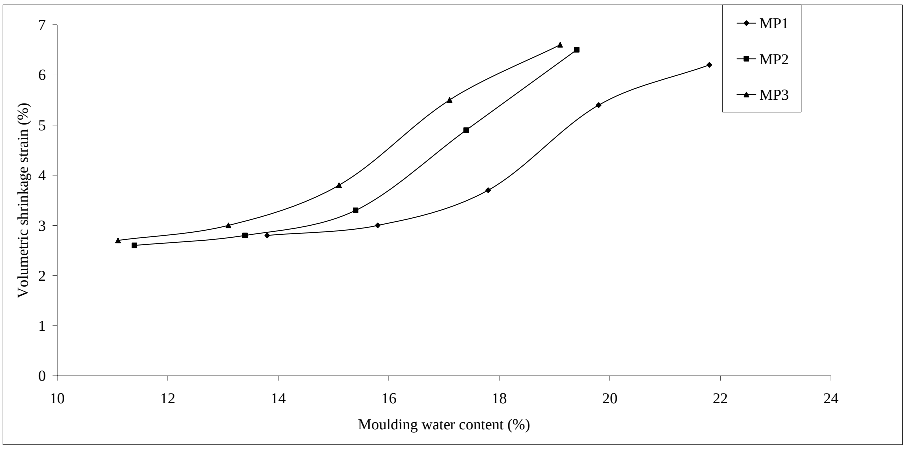

Figure 3. *Variation of volumetric shrinkage strain with moulding water content*

In Figure 4, all specimen prepared at 2 and 4% wet of optimum did not meet the regulatory maximum VSS value of 4%, while all specimens prepared at 2% dry of optimum and at optimum moisture content met the regulatory value. At dry of optimum, soils are always flocculated (i.e., random particle arrangement), whereas at wet of optimum, the fabric becomes more oriented or dispersed [20]. Also, specimens compacted at higher moulding water content shrunk more during drying and this is consist with reported results [18, 19, 20]. This is so because drying shrinkage in fine-grained soils according to [26; 21] depends on particle movement as a result of pore water tension developed by capillary menisci. If two samples of a given clay are at the same initial water content but different fabrics, the one that is more deflocculated and dispersed shrinks more which is due to average smaller pore sizes, allowing greater capillary stresses and easier relative movement of particles and particle groups. Hence, these results agree with those of earlier studies that soils with liquid limit or free swell less than 50% exhibit small volume changes [15, 10].

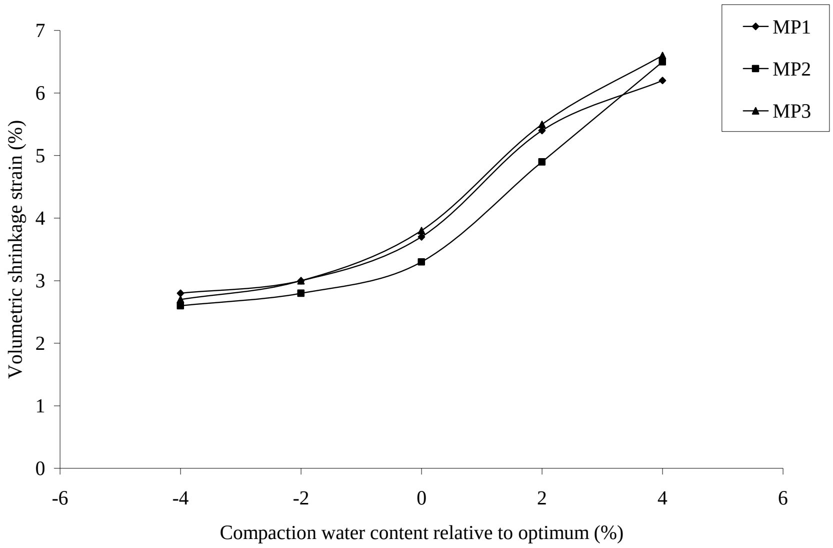

Figure 4. *Variation of volumetric shrinkage strain with compaction water content relative to optimum*

Effect of Dry Unit Weight

The variation of volumetric shrinkage strain (VSS) with dry unit weight is shown in Figure 5. It was observed that VSS increased with higher dry unit weight and further increased after the dry unit weight decreased in values that correspond to those recorded on the wet side of optimum in agreement with [10].

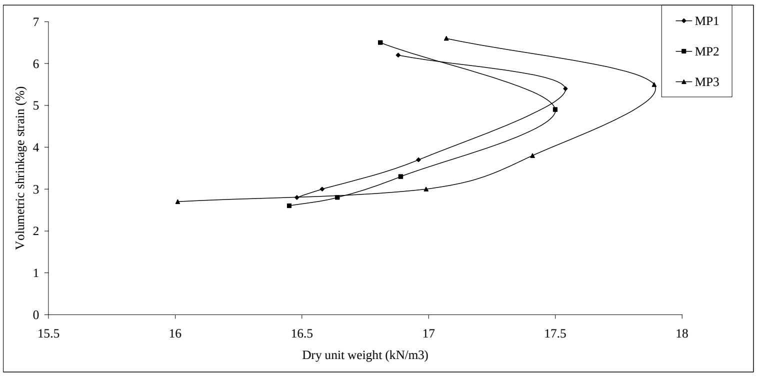

Figure 5. *Variation of volumetric shrinkage strain with dry unit weight*

Effect of Initial Degree of Saturation

The variation of volumetric shrinkage strain with initial degree of saturation is shown

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in Figure 6. VSS increased with higher initial degree of saturation up to 78, 81 and 82% for MP1, MP2 and MP3, respectively. At higher initial degree of saturation there was more water in the soil, hence more capillary tension since particles were more deflocculated and it was relatively easier for particles to move, leading to increased shrinkage. The results obtained are in agreement with those earlier reported [10].

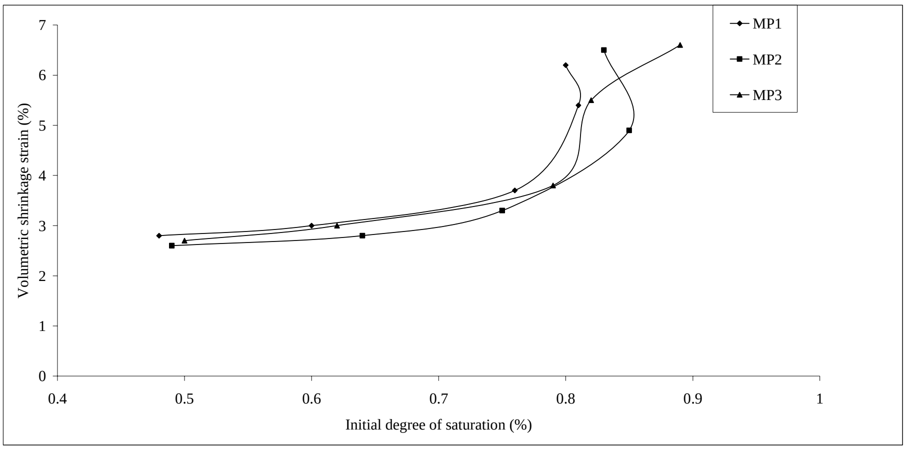

Figure 6. *Variation of volumetric shrinkage strain with initial degree of saturation*

Conclusion

Laboratory tests were carried out on three compacted reddish-brown tropical soils from Moniya, Ibadan south-western Nigeria, to investigate their induced volumetric shrinkage when used in waste containment applications. The soil samples, which were classified as A-7-6 and CL (lean clay with sand) in accordance with AASHTO and USCS, were compacted using standard Proctor energy.

Specimens prepared at moulding water contents in the ranges 13.8 – 21.8%, 11.4 – 19.6% and 11.1 – 19.1% for soils MP1, MP2 and MP3, respectively, recorded volumetric shrinkage strain values less than the regulatory 4%. Specimens compacted at higher moulding water content (i.e., 2 and 4% on the wet side of the optimum) had the highest volumetric shrinkage strain values. It is recommended that samples are to be compacted near optimum water content and at dry unit weight which should not be less than 16.01kN/m^3 in order to satisfy the volumetric shrinkage strain less than 4% regulatory standard for use of the material in waste containment applications.

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