Acceptable Zone for Reddish Brown Tropical Soil as Liner Material.

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ABSTRACT

This paper presents the findings of laboratory tests that were carried out on reddish brown tropical soil from Moniya, Ibadan, Southwestern Nigeria, to determine its potentiality as hydraulic barrier material. Three soil samples were collected (labeled MP1 - MP3) and compacted at –2, 0, 2, and 4% of optimum moisture content using four compactive energy levels namely Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS), and British Standard Heavy (BSH). The design parameters namely: hydraulic conductivity, volumetric shrinkage, and unconfined compressive strength showed appreciable variations in their respective values as molding water contents and compactive efforts were varied. The soil samples studied had hydraulic conductivity that was less than or equal to 1×10^{-7} cm/s provided that: the initial dry unit weight is greater than or equal to 16.10 kN/m^3; the initial degree of saturation is greater than or equal to 85%; compaction is carried out at a compactive effort greater than or equal to that of the standard Proctor. Hence, the samples can be used as hydraulic barrier in waste containment structure.

(Keywords: compactive effort, reddish brown tropical soil, design parameters, hydraulic barrier)

INTRODUCTION

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 (WHO, 1987). It was argued that improvement in water supply alone will have little effect on health if sewage is still accumulating in and around the home (Mohanty et al., 2002). Currently in most developing countries, particularly in Nigeria, there is no cost-effective technology for the reuse and recycling of municipal solid waste (MSW).

Many communities in Nigeria rely on surface and groundwater as a primary source of drinking water of which a variety of threats to its quality exist. Rapid industrial development in developing countries has increased hazardous waste generation several-fold. Heavy metals, organic compounds and other toxic effluents continue to be deliberately released into the environment by manufacturing, mining, oil production, etc.

Streams and other sources of domestic water consumption, especially those in rural areas, are now known to have recorded lethal levels of toxicity with attendant risks to human lives (Benson, 1999; Frempong and Yanful, 2006; 2008). Although there are some efforts to reduce and recover the waste, disposal in landfills is still the most common method for waste disposal. Subsurface pollution from these wastes occurs when water that has leached potentially harmful chemical species migrate through these waste ultimately reaches the environment beneath the waste. The amount and quality of the contaminated water generated by the waste depends primarily on the physical and chemical properties of the waste involved.

Guidelines for MSW landfills were first issued in 1959 by the American Society of Civil Engineers. These landfills were constructed to replace open dumps. One good method of controlling/preventing groundwater contamination is to place the waste material in an engineered waste containment facility with a liner and cover (hydraulic barrier).

The primary purpose of the liner system is to prevent/minimize the migration of leachate directly into the underlying soil during both the active disposal period as well as the post-closure or inactive period which assume more importance than the cover system in that it prevents the generation of leachate minimizing the amount of precipitation, percolating through the waste (Daniel, 1993; Benson, 1999; Bello, 2013a,b; Bello et al., 2015).

The suitability of a material for constructing a liner (or cover) depends primarily, on low hydraulic conductivity (generally less than 1 x 10^{-7} cm/s), durability and resistance to weathering, constructability and compatibility with the leachate (Edil et al., 1992). Natural liners have the following attributes which make them suitable as liners system: they contain significant amounts of clay minerals and have hydraulic conductivities less than or equal to 1 x 10^{-7} cm/s; the material should have adequate shear strength (a minimum Unconfined compressive strength of 200 kN/m^2) and be durable to withstand the destructive forces of alternating wet/dry and freeze/thaw cycles (Daniel and Wu, 1993; Edil et al., 1992). A maximum allowable value of 4% volumetric shrinkage of compacted cylinder upon drying has been adopted by some investigators - (Daniel and Wu, 1993).

Clay liners typically serve as a back-up to geosynthetic liners, but occasionally (for old landfills or, where regulations allow, for new landfills), a natural liner may represent the only liner at a waste disposal facility. Soils rich in clay minerals are used for constructing compacted soil liners because they have low hydraulic conductivity and can attenuate inorganic containments (Benson and Trast, 1995). A variety of natural processed soil and/or geosynthetic materials have been used for constructing the liners of waste containment systems. Highly plastic clays, clayey soils of low plasticity, sand-bentonite mixtures, sand-kaolinite mixtures, bentonites, pozzolanic fly ash or pozzolanic fly ash-sand mixtures, bagasse ash mixture, blast furnace slag, geosynthetic clay liners, geomembrane liners, foundry green sands, laterite-bentonite mixture, laterite-bagasse ash mixture, etc (Edil et al., 1992; Benson and Trast, 1995; Mollins et al., 1996; Abichou et al., 2000; Albrecht and Benson, 2001; Osinubi and Amadi, 2010; Osinubi and Eberemu, 2010) are examples of materials used as liners and covers in waste containment structures.

Thus, the main purpose of soil liners and covers is to serve as hydraulic barriers to impede flow of fluids and contaminants across them. They are therefore designed to have (1) low hydraulic conductivity, (2) minimal desiccation-induced volumetric shrinkage, and (3) adequate shear (or in general mechanical) strength to ensure their structural integrity. Laboratory evaluation of soils to be used as hydraulic barriers will usually involve hydraulic conductivity, volumetric shrinkage, unconfined compressive strength as well as indirect tensile strength tests on compacted soil specimens. As a result of this, this research investigates the acceptable zone of Reddish Brown tropical soil from Moniya, Ibadan, Southwestern Nigeria to determine its potentiality for hydraulic barriers.

MATERIALS AND METHOD

Sampling of Soils

The method of disturbed sampling was employed in obtaining soil samples for laboratory testing. The soil samples were obtained at depths of 0.80 – 2.90 m for Moniya 1, 2, and 3 designated as MP1, MP2 and MP3. The soil samples were collected in large-to -medium-sized bags and thereafter transported to the Soil Mechanics Research Laboratory of the Department of Civil Engineering, Ahmadu Bello University (ABU), Zaria. Each soil sample was spread and allowed to air-dry under laboratory conditions.

Compaction

The sample specimens tested were prepared by mixing the relevant quantity of dry soil samples previously crushed to pass through BS No.4 sieve with 4.76 mm aperture as outlined by Head (1992) as well as Albrecht and Benson (2001). The specimens were molded at water content in the range 5.25 - 25.5% and four different compactive efforts similar to those that might be achieved in the field.

The compaction methods used included the reduced Proctor (RP) effort described by Daniel and Benson (1990) as well as Benson and Trast (1995) which is equivalent to the Reduced British Standard Light (RBSL). The standard Proctor (SP) or British Standard Light (BSL) and modified Proctor (MP) or British Standard Heavy (BSH) are in accordance with BS 1377 (1990). The West African Standard (WAS) compaction is outlined in the Nigerian General Specification (1997).

Five to seven batches of soil each weighing 2.5 kg was placed in a tray and mixed with tap water. The reduced and standard Proctor compactions utilized 3 layers applying 15 and 27 blows each of a 2.5kg rammer falling from a height of 300mm using 1000cm^3 mold, respectively. The modified

Proctor compactive effort involved the use of the same mold with a 4.5 kg rammer falling from a height of 450 mm applying 27 blows each and compacting in 5 layers. For the West African Standard compactive effort which is the conventional energy level commonly used in the region (Ola, 1980; Osinubi, 1998) consist of energy level derived from a 4.5 kg rammer falling through 450 mm height onto five layers using 10 blows each.

Design Parameters

Materials for landfill liners/covers are usually investigated for a number of parameters which are considered to be relevant to their proper functioning under service condition. The design parameters investigated in this study include hydraulic conductivity, desiccation-induced volumetric shrinkage and unconfined compressive strength of the materials (i.e., soil). Other parameters that must be considered in clay liner design include indirect (splitting or Brazilian) tensile strength, bearing capacity, trafficability, internal and interface shear strengths as well as compressibility (Benson et al., 1999). However, in this investigation, only the three afore-mentioned design parameters have been considered.

Hydraulic Conductivity

Air-dried soils specimens for hydraulic conductivity tests were first mechanically crushed to smaller sizes enough to pass through 4.76 mm aperture (BS No. 4 sieve size). The test specimens were mixed with ABU, Zaria tap water to the desired molding water contents. The hydraulic conductivity tests were carried out in rigid-wall compaction mold parameters using the falling head method similar to the method reported by Daniel and Wu (1993). Samples compacted at optimum (0%), two (2%) and four (4%) dry (-) and wet (+) of the optimum using the four compactive efforts were soaked for at least 48 hours to achieve full saturation in accordance with Head (1992).

Compacted specimens together with compaction molds were first placed in immersion tanks and water was gradually introduced such that the top of the compacted soil was covered with about 3-5 cm of water. The placement of the compacted specimen and mold in the immersion tank was to ensure that there would not be any drying of the sample specimen from the lower open end of the mold. A relatively short sample was connected to a stand pipe, which provided both the head of water and the means of measuring the quality of water flowing through it. After saturation, test specimens were connected to a permeant liquid (distilled water). Readings were taken intermittently and the changes in water height under 8 hours intervals were measured. Permeation was terminated when the hydraulic conductivity values were generally within 10% of the average values or when steady state condition was reached for the more permeable specimens. The geometric mean of the last three readings were computed and reported as the hydraulic conductivity of each of the thirty (30) samples.

Strength

Unconfined compressive strength (UCS) tests were conducted on soil specimens previously mixed with ABU Zaria, tap water and compacted at molding water contents in the range 5.25 - 25.5% using four compactive efforts. Compacted specimens were sealed in plastic lugs and allowed to stand for at least 24 hours before trimming (for UCS test specimens) and testing. Each strength test involved the use of sixty (60) specimens. At least two trimmed specimens (38 mm diameter by 76 mm high) per molding water content per compactive effort were used in the UCS testing.

Volumetric Shrinkage

Sixty (60) sample specimens were compacted using four different compactive efforts at optimum moisture content (OMC), two and four percents dry and wet of the optimum molding water content. These samples were carefully extruded from the 1000 cm^3 molds and left on a table to dry gradually at laboratory room temperature 25 ± 2^0C. The weights and dimensions of the specimens were measured regularly for 28 days until when no change in the dimensions or weights were observed.

Design of Overall Acceptable Zones

Daniel and Benson (1990) described a procedure for developing the compaction criteria for soil liners and covers and it involves:

(1) Compacting and permeating a soil over ranges of molding water contents and compactive efforts as well as definition of an acceptable zone of suitable molding water contents and corresponding dry unit weights.

(2) Modifying the acceptable zone already delineated on the basis of hydraulic conductivity using appropriate geotechnical parameters such as volumetric shrinkage strain and soil strength.

This procedure which was employed by Daniel and Wu (1993) for clayey sand was used in this study. The following three conditions were established here:

(a) The compacted soil should have a low hydraulic conductivity, with 1 x 10^{-7}cm/s as the maximum allowable value for soil liners and covers (Daniel and Benson, 1990)

(b) In the absence of any other definitive value, 4% volumetric shrinkage strain of compacted soil cylinders upon drying (Daniel and Wu, 1993; Albrecht and Benson, 2001) is assumed to be the maximum allowable for soil specimen. Soils with minimal volumetric shrinkage upon drying are considered to have minimal potential to crack upon drying.

(c) A minimum unconfined compressive strength of 200kN/m^2 which is the lowest value for very stiff soils based on a classification by Peck et al. (1974) was used in this study. It is considered necessary that compacted lateritic and abandoned dumpsite soils liners and covers should have adequate strength in order to ensure their structural integrity. Osinubi and Nwaiwu (2002) have shown that once the unconfined compressive strength condition is satisfied, the tensile strength condition is also satisfied; only unconfined compressive strength is used in defining the acceptable zones for the soil specimen under consideration.

RESULTS AND DISCUSSION

Delineation of Acceptable Zone

The development and execution of a construction quality assurance plan has been described as the basis on which the successful design and construction of hydraulic barriers is based. According to Daniel and Benson (1990), most engineers rely primarily on field-measured water content and dry unit weight to verify proper compaction of the soil. Benson and Boutwell (1992) identified two compaction criteria: the common and the modern criteria. Daniel and Benson (1990) reviewed the common compaction control criterion (i.e., traditional approach to construction quality assurance) and described procedures for establishing quality assurance using the modern criterion. For the purpose of this research, the modern approach was used.

Acceptable Zones Based on Modern Criterion

The acceptable zone in this case is usually established first with hydraulic conductivity as the primary design parameter. Daniel and Benson (1990) have worked on a certain procedure which was used by Daniel and Wu (1993) to develop the hydraulic conductivity-based acceptable zones as shown in Figure 1a-c, while that of the one based on shear strength is shown in Figure 2a-c.

Also, those based on desiccation-induced volumetric shrinkage are shown in Figure 3a-c. The hatched zones indicate portions on the compaction plane showing the limits based on different criteria for the acceptable zones.

Design of Overall Acceptable Zones Based on Modern Criterion

The acceptable zones based on desiccation-induced volumetric shrinkage strain and strength conditions were superimposed on the earlier defined acceptable water content/dry unit weight ranges which were based on hydraulic conductivity only.

This procedure is in conformity with the suggestions of Daniel and Benson (1990) and agrees with that employed by Daniel and Wu (1993). The results of the superimposition are shown in Fig. 4a-c.

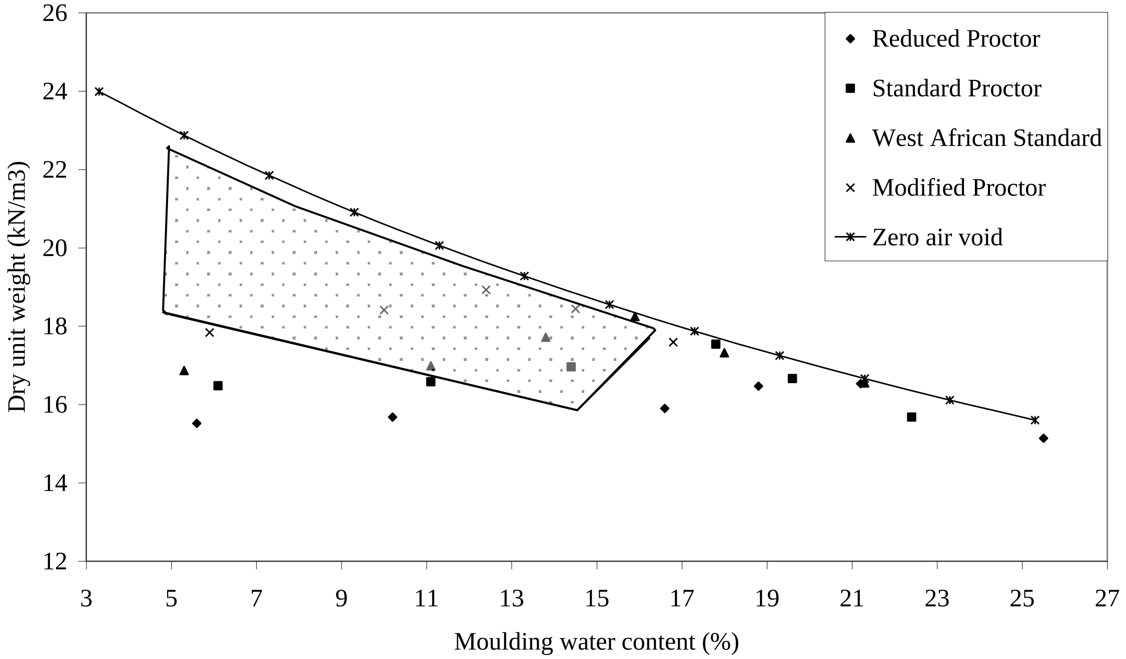

Figure 1a: Acceptable Zone based on Hydraulic Conductivity for AB1.

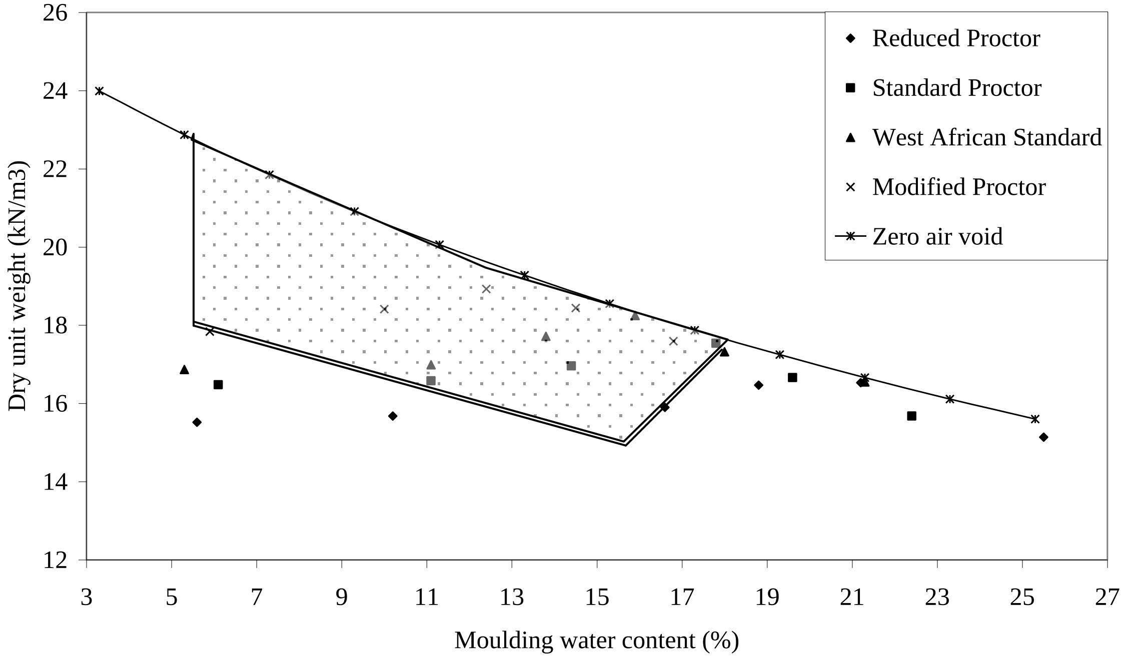

Figure 1b: Acceptable Zone based on Hydraulic Conductivity for AB2.

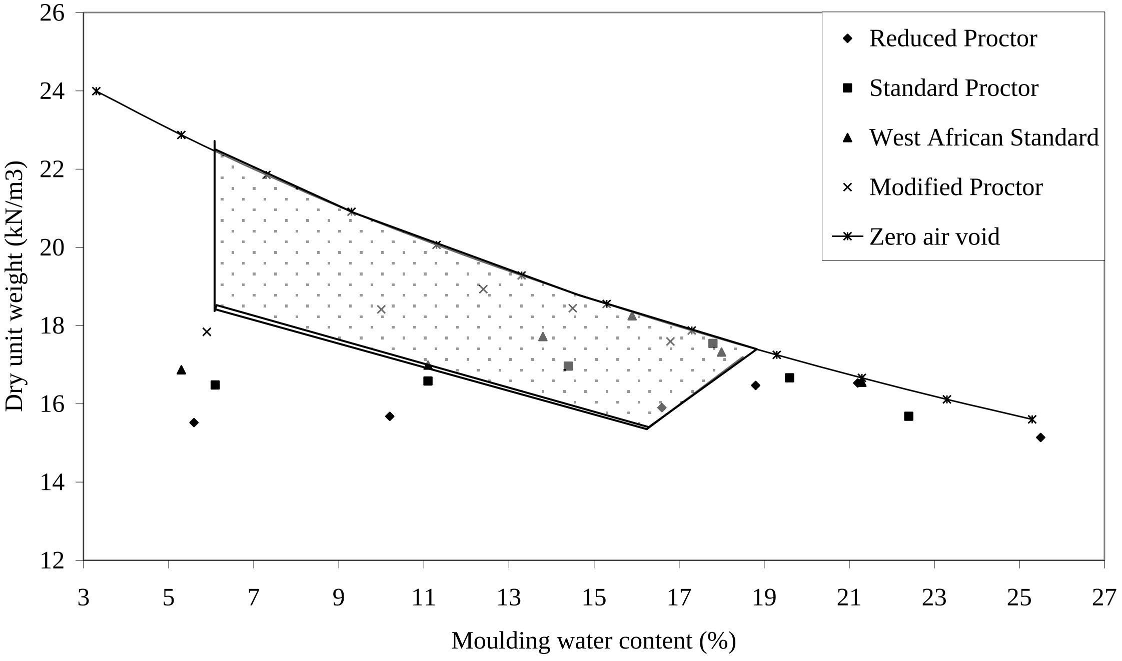

Figure 1c: Acceptable Zone based on Hydraulic Conductivity for AB3.

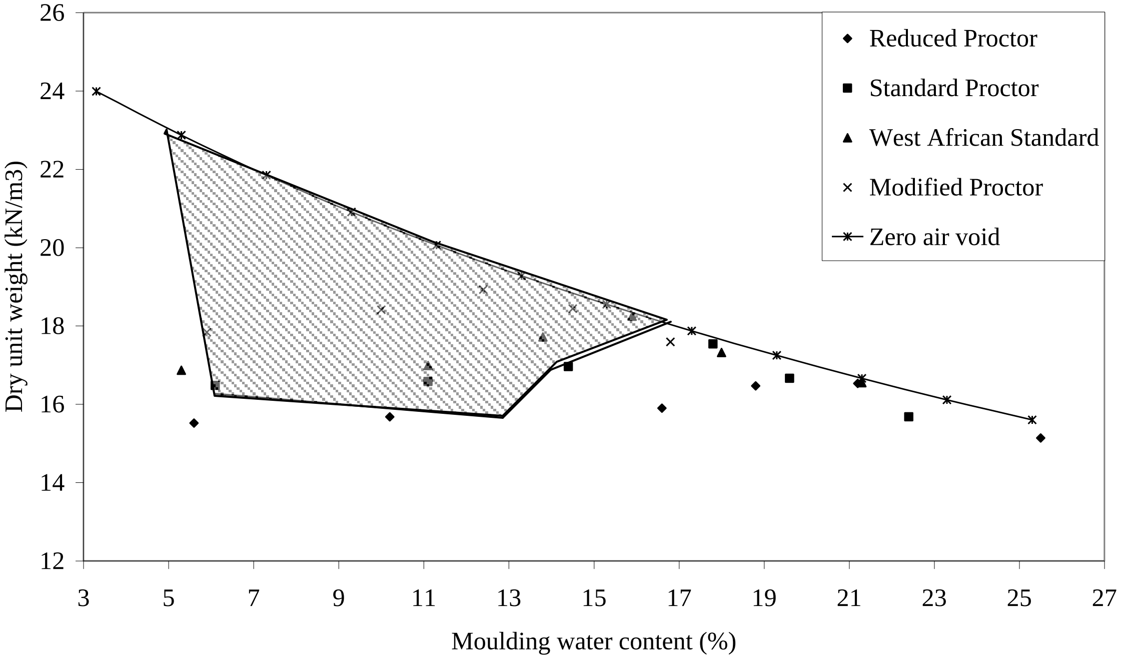

Figure 2a: Acceptable Zone based on Shear Strength for AB1.

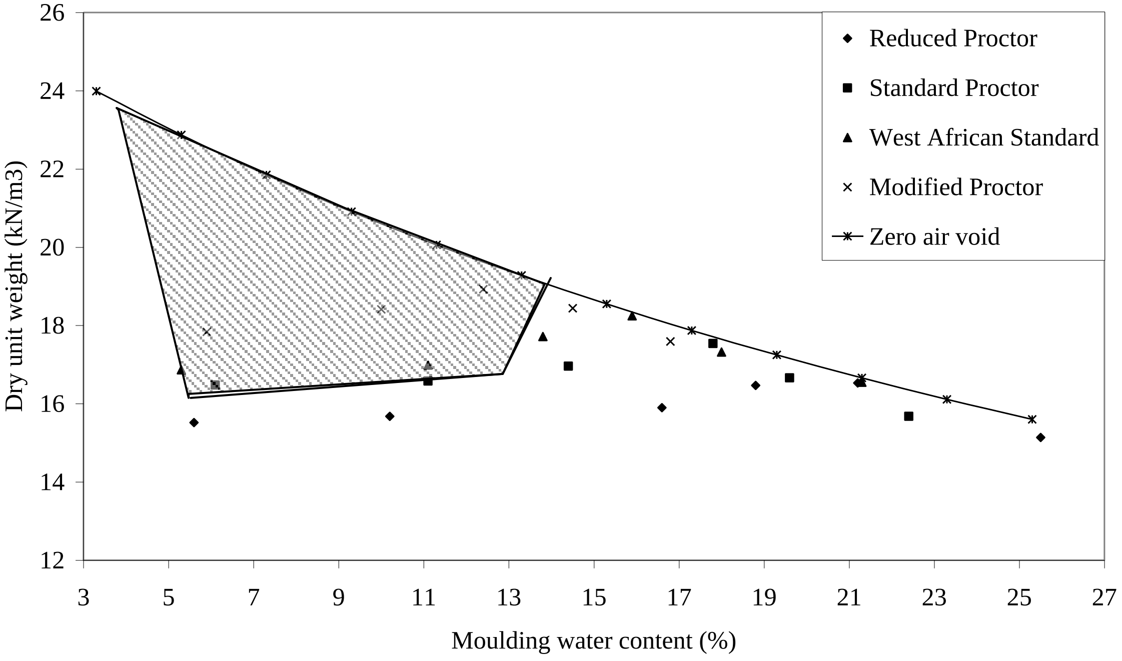

Figure 2b: Acceptable Zone based on Shear Strength for AB2.

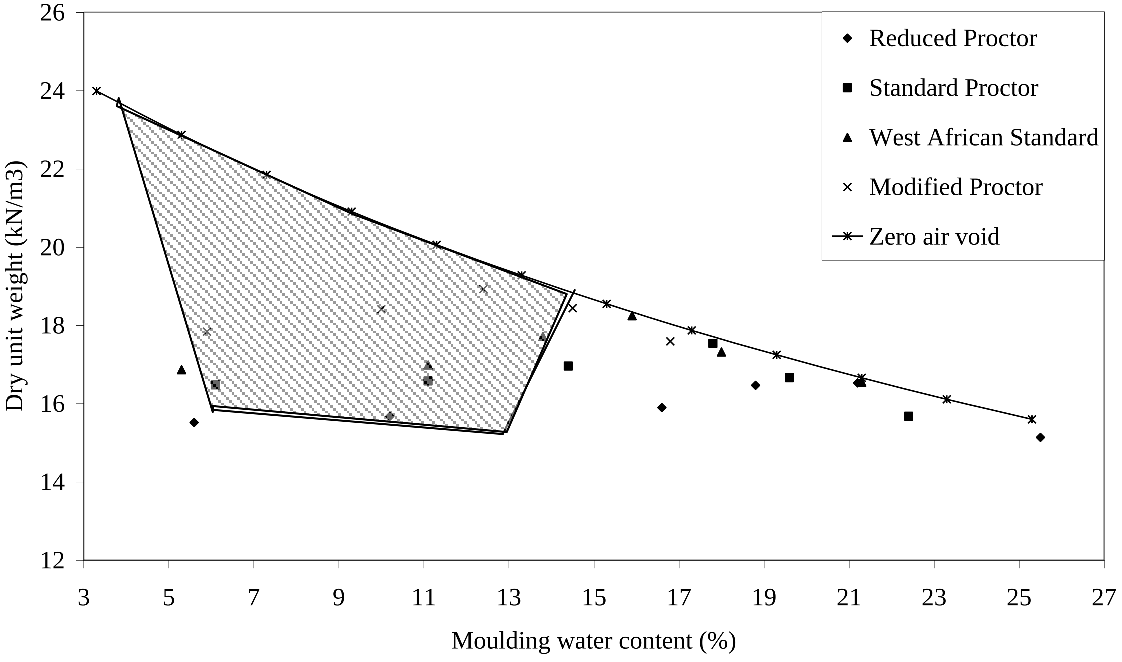

Figure 2c: Acceptable Zone based on Shear Strength for AB3

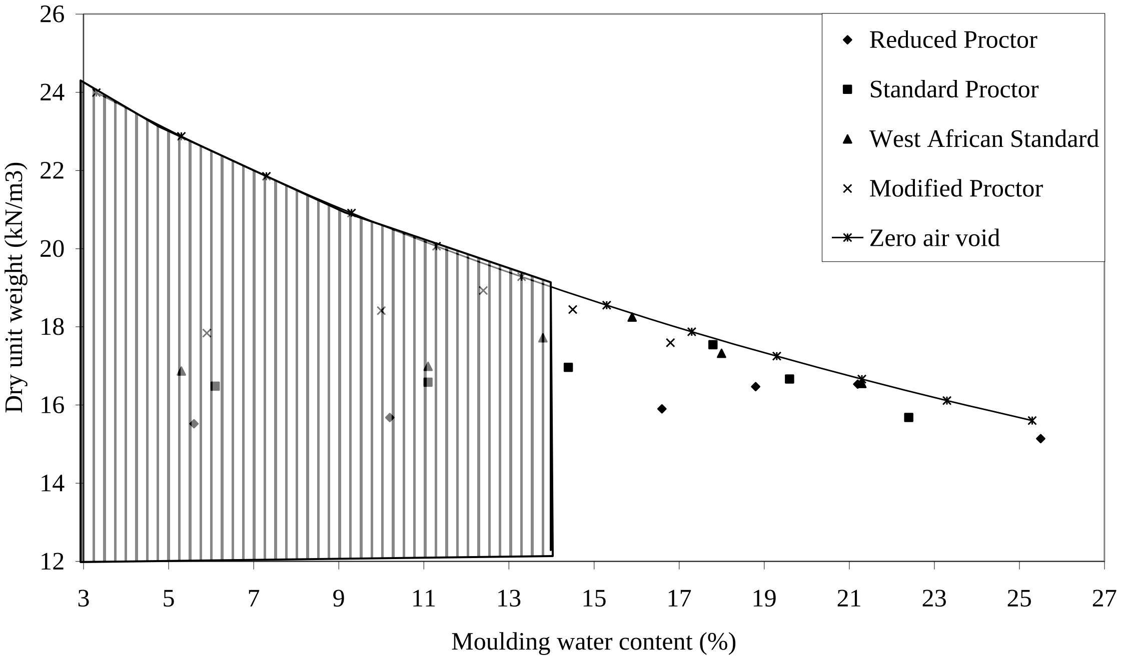

Figure 3a: Acceptable Zone based on Volumetric Shrinkage for AB1.

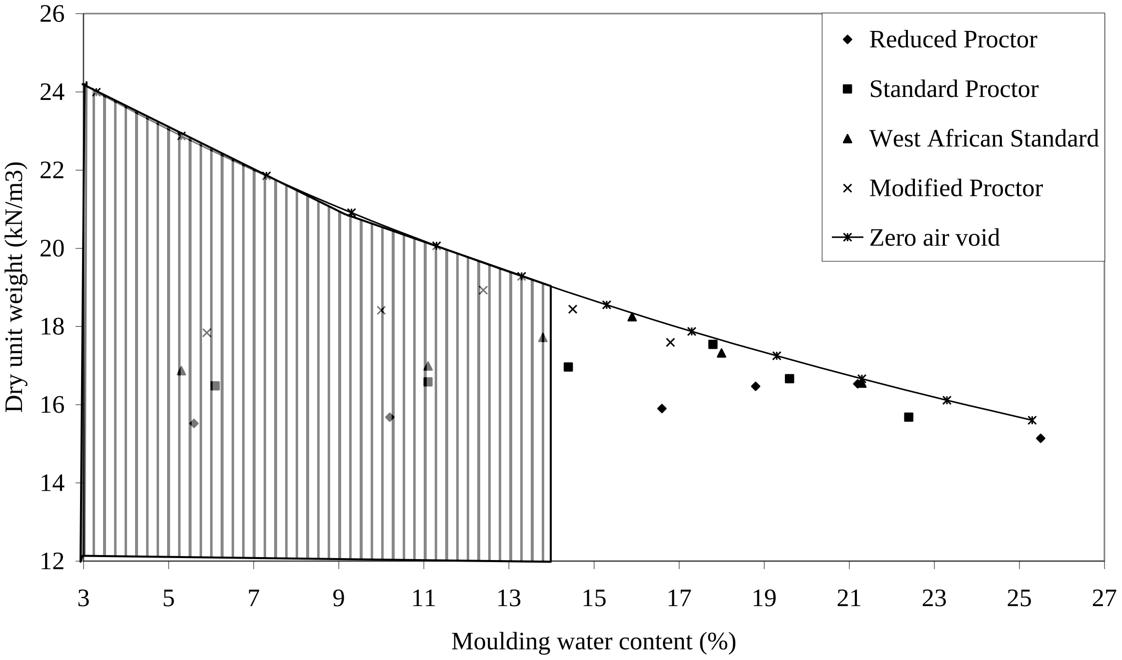

Figure 3b: Acceptable Zone based on Volumetric Shrinkage for AB2.

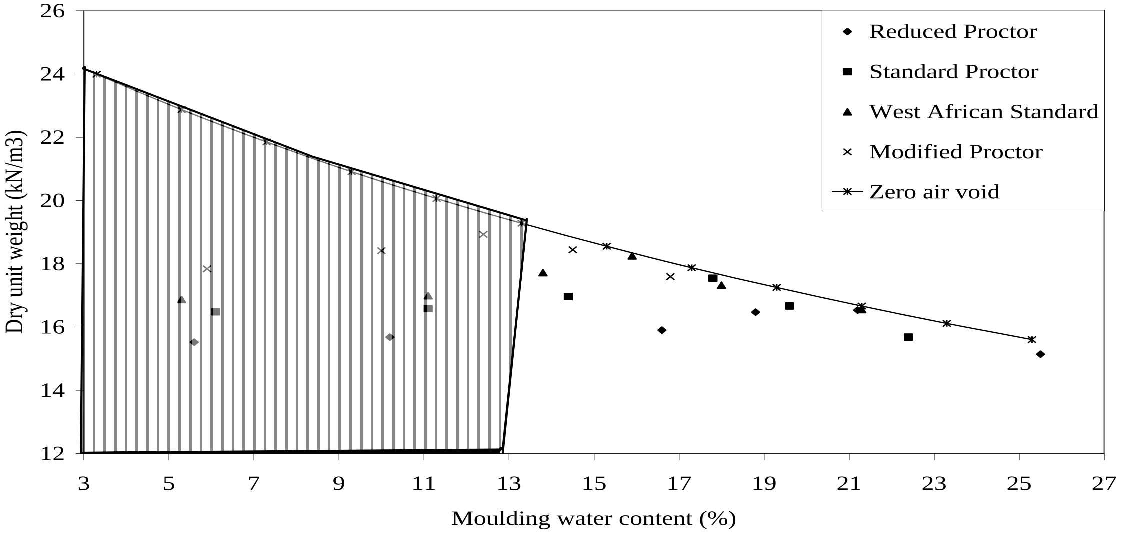

Figure 3c: Acceptable Zone based on Volumetric Shrinkage for AB3.

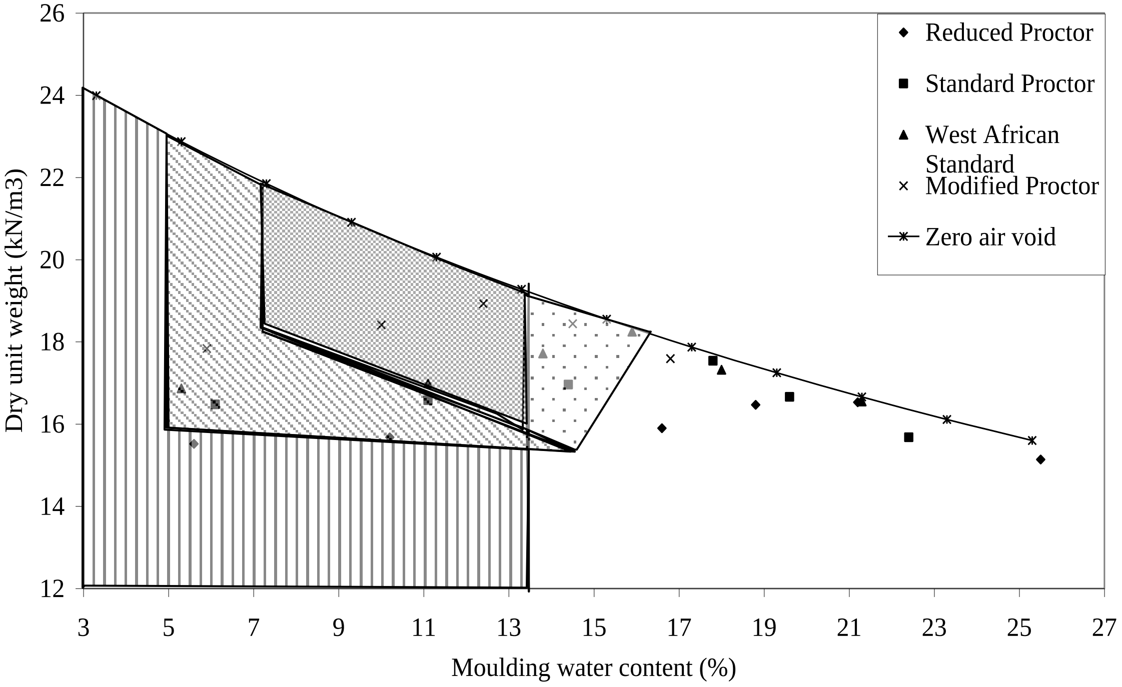

Figure 4a: Acceptable Zone for AB1 based on Low Hydraulic Conductivity, Low Desiccation Induced Shrinkage and High Unconfined Compressive Strength.

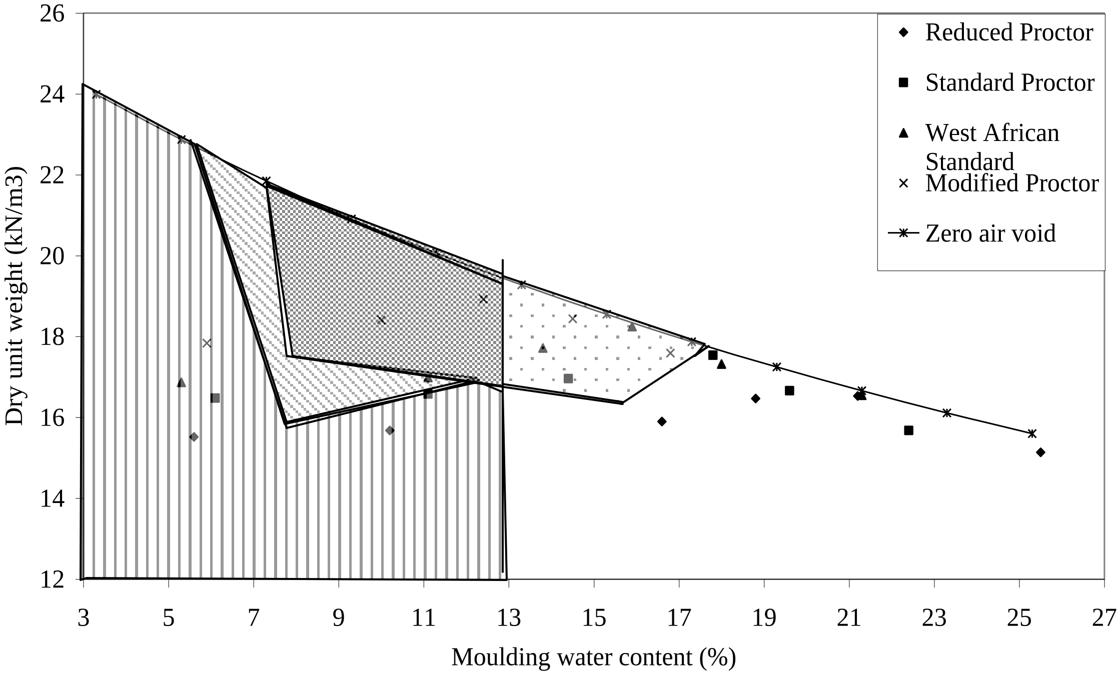

Figure 4b: Acceptable Zone for AB2 based on Low Hydraulic Conductivity, Low Desiccation Induced Shrinkage and High Unconfined Compressive Strength.

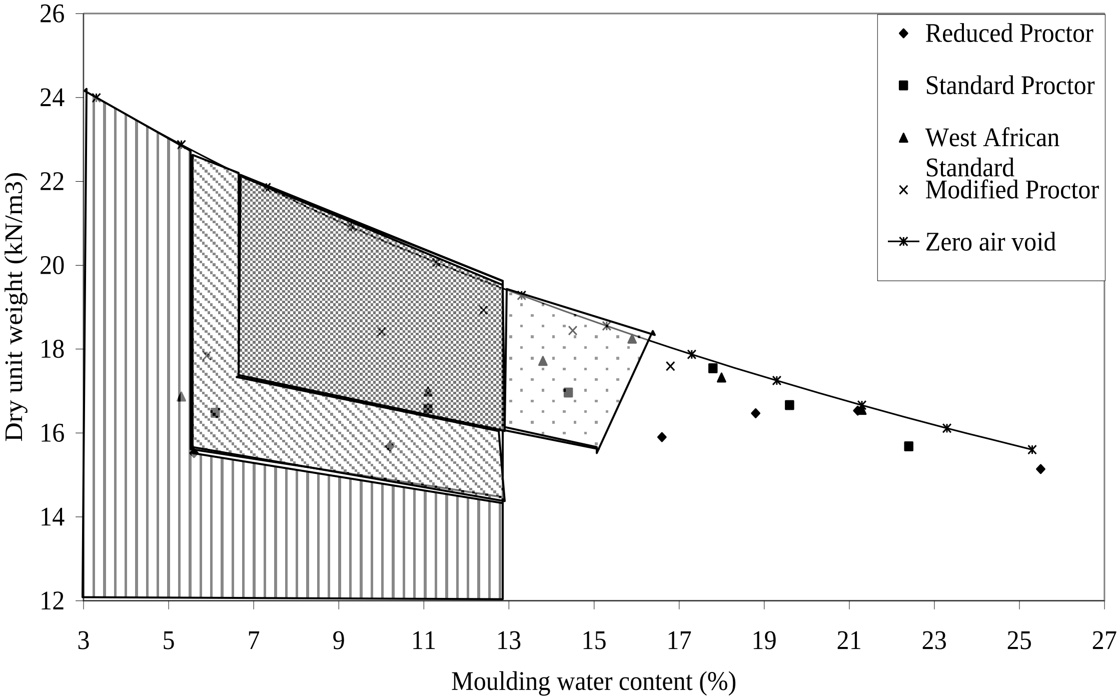

Figure 4c: Acceptable Zone for based on Low Hydraulic Conductivity, Low Desiccation Induced Shrinkage and High Unconfined compressive strength

CONCLUSION

Soil samples were compacted at –2, 0, 2, and 4% of optimum moisture content using four compactive energy levels namely Reduced British Standard Light (RBSL), British Standard Light (BSL), West African Standard (WAS) and British Standard Heavy (BSH). The design parameters namely: hydraulic conductivity, volumetric shrinkage and unconfined compressive strength showed appreciable variations in their respective values as molding water contents and compactive efforts were varied.

The soil samples studied had hydraulic conductivity that was less than or equal to 1 x 10^{-7}cm/s provided that: the initial dry unit weight is greater than or equal to 16.10 kN/m^3; the initial degree of saturation is greater than or equal to 85%; compaction is carried out at a compactive effort greater than or equal to that of the standard Proctor. Hence, the samples can be used as hydraulic barrier in waste containment structure.

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