Analysis of Swelling Behaviour of Lateritic Soil Treated with Bentonite

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Abstract

In this study, the magnitudes of swell parameters namely free swell and swell pressure of a representative lateritic soil treated with 0, 2.5, 5, 7.5 and 10% bentonite and compacted with British Standard heavy (BSH) effort were measured as the initial degree of saturation of soil mixtures were varied from 2% dry of optimum to 2% wet of optimum moisture content. Results indicate that the soil mixtures are qualitatively classified as low to medium swelling soils (PI < 35; free swell < 50) using existing classification charts in the literature. Both free swell and the swelling pressure of the soil mixtures increased approximately linearly with increase in the amount of bentonite but decreased with increasing degree of saturation of specimens. Data developed in this study will provide an understanding of the swelling capacity of soil mixtures for the most efficient placement of material in the field.

Keywords: Bentonite; Lateritic soil; Swelling characteristics; Volume change; Waste containment

Introduction

Soil swelling is a complex phenomenon with significant consequences for soil–structure interaction. It constitutes a global problem in construction such as highways and shallow foundations particularly in the arid and semi arid regions. The resultant swelling effects are often large enough to cause considerable distress or instability to lightly loaded engineering structures. Structural damage caused by swelling of expansive clays such as cracks in masonry fences, grade beams, and members of reinforced concrete, uplift of floating slabs on grade and heave of pavements and walkways is well documented in the literature (Chen, 1988; Al-Rawas and Goosen, 2006) and is aggravated when the underlying soils are periodically and (or) differentially wetted.

Notwithstanding these shortcomings, high swelling potential of clayey soils is favourable and desirable in relation to their use in the construction of some geotechnical structures such as cores of zoned earth dams, hydraulic caps and barriers for hazardous waste containment and other environmental isolation tasks. In liners of waste containment structures for example, the design concept should satisfy the requirements for the sealing performance with respect to filling cracks or gaps between the barrier material and host soil. High swelling capacity will be needed to achieve low permeability and sealing capabilities but the swelling pressure should not be too high to avoid excessive load on the surrounding soil (rock).

Based on some favourable geotechnical properties such as greater chemical resistance and low susceptibility to desiccation shrinkage (Osinubi and Nwaiwu, 2008), lateritic soil, a residual soil found in abundance in the tropical and sub tropical climates met the requirements as material for hydraulic structures. However, due to the predominance of non expanding kaolinite clay mineral, the soil generally

...hibits only a small degree of hydration and ...elling potential as well as moderately high ...meability failing to satisfy the criteria with ...spect to sealing functions. These shortcomings ...at beset the use of this soil for such ...plications can be properly addressed by ...hancing the two major properties that ...ntribute to sealing performance i.e., hydraulic ...nductivity and swelling with bentonite ...dition.

The swelling and sealing characteristics ...f bentonite have made it a popular soil ...endment for this type of application ...itchell, 1993; Amadi, 2009). It is a highly ...stic clay which contains large quantity ...pically 60–90%) of montmorillonite. In the ...sence of water, montmorillonite clay mineral ...n swell to as much as 20 times its own volume ...dharan and Choudhury, 2002). This high ...elling potential of montmorillonite is ...ributed to adsorption of hydrated cations and ...er molecules, resulting in strong repulsive ...es and interlayer expansion in the presence ...f electrolyte solutions (Mitchell, 1993; ...haran and Choudhury, 2002). In addition, ...ble-layer swelling can occur due to ...rlapping of diffuse double layer in between ...icles and also in between elementary layer ...tchell, 1993).

...e primary factors contributing to the high ...lling potential of montmorillonite relative to ...r clay minerals, such as illite and kaolinite, ...de a relatively high specific surface (i.e., ...800 m2/g) and a relatively high net negative ...e as reflected by relatively high cation ...nge capacities that typically range from 80 ...meq/100g (Grim and Guven, 1978).

Therefore, to design and construct ...es with bentonite-based materials, the ...g properties which is a representation of ...ydraulic and mechanical behavior of the candidate material is one important behavior that should be investigated in the assessment of material for hydraulic functions. This is essential in order to determine the optimum bentonite requirement since improper and/or excessive use of this admixture can impart swelling effects beyond design specifications that could result in failure and to provide an understanding of the swelling capacity at the outset of construction for the most efficient placement of material in the field.

Materials And Method

Study Soil

The study soil was obtained from the upper 0.5–1.5 m of the soil profile at the site in Shika – Zaria, Nigeria (Latitude 11o15' N and Longitude 7o45' E). The soil is a natural reddish brown soil with inclusions of white mottles.

Bentonite:

The bentonite used in this study is in powdered form and was obtained from a major supplier in Lagos – Nigeria. It is a representative of typical bentonite frequently used locally for construction purposes.

Index Properties tests

The particle size distribution, Atterberg limits and compaction properties of the soil mixtures were measured in accordance with standard procedures outlined in BS 1377 (1990). The soils were air dried and pulverized sufficiently to run through the No. 40 sieve (425μm) for Atterberg limit tests and No. 4 sieve (4.76 mm) for compaction as well as swelling tests. The required percentage of tap water based on dry weight was added to obtain the desired water content (at optimum, 2% dry as well as wet of optimum moisture content) and thoroughly mixed until uniform consistency was achieved. Processed soil specimens for compaction studies were compacted with

British Standard heavy (BSH) compactive effort.

Free Swell Test:

Free swell test was conducted in conventional one dimensional oedometer apparatus (Sivapullaiah et al., 1978; Chen, 1988). In the test, soil mixtures prepared at predetermined moisture content were compacted in a consolidometer ring with British Standard heavy (BSH) compactive effort, inundated with tapwater. Silicon grease was applied to the inner surface of the ring to eliminate friction. Specimens were then allowed to swell under approximately zero vertical pressure, that is, swell plate consisting of perforated plate with adjustable stem only. Swell measurement (i.e., height) was taken at 96 hours as swelling did not occur past the 96 hours.
The percent of free swell is expressed as:

$$Free\ Swell\ (\%) = \frac{\Delta H}{H} \times 100 \qquad (1)$$

Where ΔH = Height of swell due to saturation
H = Original height of specimen

Swelling Pressure Test

Vertical swelling pressure was measured using potential volume change (PVC) meter carried out in accordance with the procedures outlined in Chen (1988) as well as Nelson and Miller, (1992). The test consists of placing a specimen compacted with British Standard heavy (BSH) effort at different compaction states (dry of optimum, optimum and wet of optimum moisture content) into a consolidometer ring. As in the free swell test, silicon grease was applied to the inner surface of the ring to eliminate friction. The samples were then inundated with tap water in the device and allowed to swell against a swell plate with a proving ring. The pressure at steady state on the proving ring measured by a digital strain meter was reported as the swelling pressure.

Results and Discussion

Index Properties results

The experimental result of the particle size characteristics for the lateritic soil sample presented in Fig. 1 indicate a fines content (combined clay/silt) of 57%. The clay mineralogy of the soil is predominantly a 1:1 lattice clay mineral (i.e. kaolinite) with non expanding lattice structure. The consistency of the natural soil determined by Atterberg limits together with specific gravity and linear shrinkage (LS) is reported in Table 1 as well as in Fig. 2. Test results presented in Fig. 2 showed increases in Atterberg limits of mixtures with higher bentonite content.

Table 1: Properties of natural lateritic soil

Characteristics	Quantity
Natural moisture content (%)	19.60
Liquid Limit (%)	42.20
Plastic Limit (%)	19.98
Plasticity Index (%)	22.22
Linear shrinkage (%)	5.56
USCS Classification	CL
Specific gravity	2.60
pH	6.67
Activity	0.92
Colour	Reddishbrown
Dominant Clay Mineral	Kaolinite

Table 2: Properties of bentonite used in the study

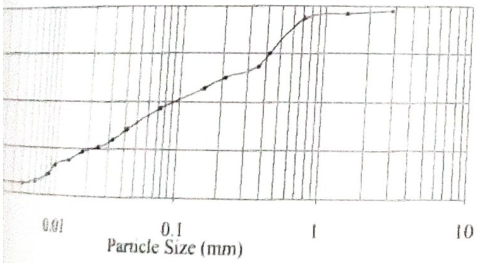
Property	Quantity
Liquid Limit (%)	250
Plastic Limit (%)	45
Plasticity Index (%)	205
Percent Passing # 200 Sieve	92
Specific Gravity	2.4
Swelling Potential	High

...ble 3: Oxide composition of lateritic soil ...d Bentonite

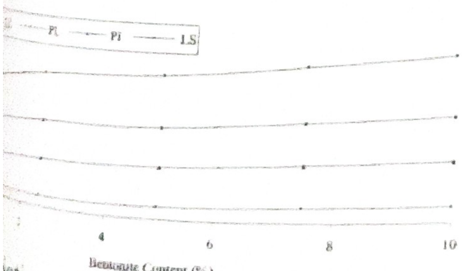
...ide	Concentration (%)	
	Lateritic soil	Bentonite
	0.28	0.86
	35.60	58.14
	27.40	21.73
	2.40	2.46
	0.22	2.42
	0.85	ND
	2.00	ND
	ND	0.52
	ND	1.86
	ND	2.08
...ss on ignition	146.00	13.28

...- Not determined

The increasing trend was expected and is ...ative of the increase in clay fraction ...onite) in the mixtures. Based on parameters ...mined from index properties, Soil mixtures ...lassified as low to medium swelling soils ...PI = 15 - 35). Mixtures containing 0 – 5% ...nite were graded as inorganic clay soils of ...asticity (CL), while mixtures with 7.5 – ...bentonite may be classified as CH soils ...the Unified Soil Classification System ...1959; Nelson and Miller, 1992).



...Particle size distributions of soil



...ation of plasticity index and linear ...th bentonite content.

Compaction Characteristics

The variations of maximum dry unit weight and optimum moisture content with bentonite content of soil mixtures determined from compaction tests are reported in Fig. 3. The maximum dry unit weight decreased, while the optimum moisture content increased with higher bentonite content. Maximum dry unit weight values were found to be in the range of 17.98 - 18.91 kN/m3 corresponding to 11.56% - 13.88% optimum water content values for different soil mixtures. These properties are in agreement with the range obtained by Amadi (2009) as well as Muntohar (2003).

Bentonite treatment resulted in the formation of gel around the soil particles and the consequent increase in effective size of soil particles as well as in void volume. In other words, there was reduction in interparticle repulsion forces and increased flocculation to raise optimum moisture content and reduce the maximum dry unit weight (Lambe, 1958)

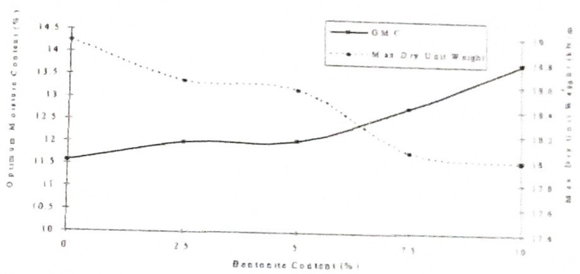


Fig. 3: Variation of maximum dry unit weight and optimum moisture content with bentonite content.

Swelling Potential

The variation in measured free swell of soil mixtures with bentonite content is illustrated in Fig. 4. The resulting trend is a general increase in free swell with higher bentonite content. This is indicative of an increase in the more active montmorillonite clay mineral found in bentonites (Low, 1981; Amadi, 2009). Free swell were determined as 25, 29.2, 34.4, 41.5 and 47% respectively for compaction dry of optimum and 16.67, 20, 23.8, 28.57 and 31.03%, respectively for optimum compaction while 15, 15.8, 17.2, 20 and 23% respectively for wet of optimum compaction for 0, 2.5, 5, 7.5 and 10% bentonite contents mixtures. Soils having free swell values greater than 100% are normally considered potential problems and can cause considerable damage to lightly loaded structures, whereas soils with free swell values below 50% probably do not exhibit appreciable volume changes even under light loading (Holtz, 1959).

For purposes of classification in terms of swelling potential, the lateritic soil - bentonite mixtures used in this study may be qualitatively classified as low to medium swelling soils (free swell < 50) based on the classification chart for expansive soils in the literature (Holtz, 1959; NBRRI, 1983).

Fig. 4 also represents the effect of initial degree of saturation on the swelling potential of soil mixtures. Mixtures compacted at initial moisture content dry of optimum were observed to have higher free swell when compared to mixtures compacted at optimum and wet of optimum moistures, hence at the same bentonite content, free swell values for dry of optimum moisture content plotted above free swell values for optimum and wet of optimum compaction. This is followed by free swell values at optimum compaction and lastly by wet of optimum compaction.

The lower values of free swell for specimens with higher degree of saturation may be expected, since as the initial water content increases, for specimens having the same bentonite content, the affinity of the mixture to absorb water diminishes. It follows that the amount of water absorbed for complete saturation will become smaller, and consequently the amount of swelling will decrease as the initial water content increases.

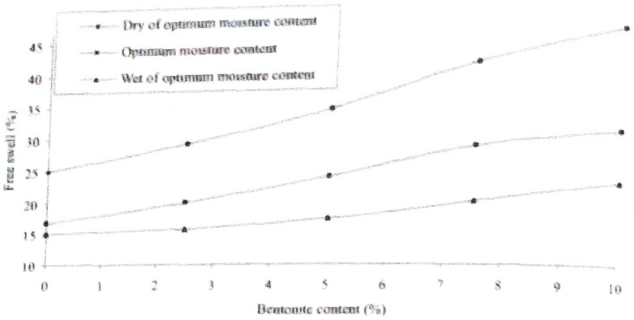


Fig. 4. Variation in swelling potential with bentonite at various compaction states

Swelling pressure

Relationships between maximum swelling pressure and bentonite content at the various compaction states are reported in Fig. 5. As indicated by the data in Fig. 5, swelling pressure is collectively a function of bentonite content and initial degree of saturation. While mixtures recorded increasing trend in the swelling pressure with higher bentonite content, reduction in values of swelling pressure were observed as the compaction state changed from dry to wet of optimum. Compaction on the dry side of optimum (i.e., at approximately 2% dry of optimum moisture content) produced swelling pressures values of 5.5, 11.6, 18.5, 22.4 and 28kN/m2 for 0, 2.5, 5, 7.5 and 10% bentonite contents respectively. At OMC, the swelling pressure values decreased to 3.2, 6.8, 15.6, 19.55 and 23kN/m2 respectively for the same sequence of bentonite application. Further reductions in the magnitudes of swelling pressures were established when samples were compacted at 2% wet of optimum moisture content. Swelling pressure values of 2.5, 3.5, 4, 6, 8.4 and 12kN/m2 were recorded for 0, 2.5, 5, 7.5 and 10% bentonite contents respectively. The observed trend is consistent with what has been reported by other investigators for clay soils treated with bentonite (e.g. Low, 1981;

Sridharan and Choudhury, 2002). The decreasing trend with increased degree of saturation is expected because clayey materials compacted dry of optimum moisture content have high water deficiency and the particles are oriented in a flocculated pattern. When given access to water, they imbibe more than samples compacted wet of optimum moisture content and swell until the internal forces are in equilibrium with their environment. This results to greater swelling pressure than when compacted at optimum or wet of optimum moisture content. Conversely, compaction wet of optimum show less tendency to swelling as well as lower swelling pressure probably because of the dispersed and more oriented soil structure (Holtz, 1959).

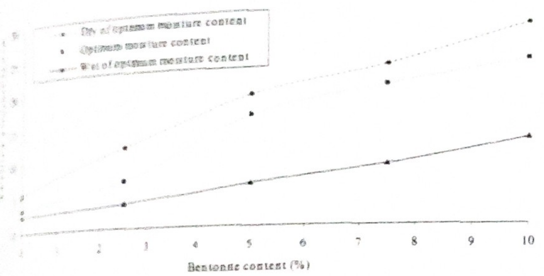


Fig. 5: Variation in swelling pressure with bentonite at various compaction states

Conclusions

In this study, the impact of variation in bentonite content and initial moisture content on the swelling parameters of lateritic soil treated with bentonite has been analyzed. Laboratory tests such as consistency limits, free swell and swelling pressure were carried out to assess the magnitudes of swell parameters in the lateritic soil treated with 0, 2.5, 5, 7.5 and 10% bentonite content compacted with BSH effort at various compaction states namely 2% dry of optimum moisture content, at optimum moisture content and 2% wet of optimum moisture content. From the test results, it was established that the free swell and swell pressures of soil mixtures increased almost linearly with the amount of bentonite but decreased with increasing degree of saturation of specimens. Based on the classification chart for expansive soils, the soil mixtures were classified as low to medium swelling soils.

The data developed in this study will provide an understanding of the swelling capacity of soil mixtures for the most efficient placement in the field and in addition guide against improper/ or excessive use of the additive to avoid excessive mechanical stress that could result in failure.

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