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Effect on Salak Tinggi residual soil mixed Bentonite as compacted clay liner

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Abstract. This paper present the result from experimental studies on using bentonite mixed with residual soil. The entire testings were performed on Salak Tinggi residual soil mixed with various percentage of bentonite content (5%, 10% and 15%). A series of laboratories were performed to investigate the effectiveness of mixed samples associated to physical properties testing such as: particle size distribution, *pH*, plastic index (*PL*), liquid limit (*LL*), plasticity index (*PI*) and linear shrinkage (*LS*). Meanwhile the standard proctor compaction test was conducted on mixed soil-benonite samples to determine the maximum dry density (MDD) and optimum moisture content (OMC). In addition the permeability test to determine the hydraulic conductivity was conducted at MDD condition at effective stress of 100 kPa. It was found that the addition of bentonite to the Salak Tinggi residual soil changed the physical properties result. Meanwhile, compaction results show a decrement in the MDD with increment of bentonite percentage mixed. The result also showed the bentonite mixed decreases the hydraulic conductivity value ($k < 1x10^{-9}$ m/s) for Salak Tinggi soil significantly. This finding shows that by using the small amount of 5% bentonite significantly can be used as compacted of soil liner materials.

1. Introduction

Residual soils are widely distributed over the globe covering and it's covered especially in tropical climate country. Malaysia is a tropical climate and humid country had residual soil broadly distributed and its covers more than quarters of the land area of Peninsular Malaysia [1]. Thus, residual soils have been used extensively in various earthwork projects, as a construction material and it suggests as a municipal landfill area are mainly constructed on residual soil.

Therefore, major concern issues for residual soils in tropics area are not feasible as compacted clay liner (CCL) application due to varies in characteristics. In current practices, there is different kind of clay liners used during the construction of landfill areas, such as inorganic clays or clayey soils due to have low hydraulic conductivity. In Malaysia, Compacted Clay Liners (*CCL*) and Geo-synthetic Clay Liners (*GCL*) are commonly used as a protective layer on residual soil surface in order to prevent groundwater contamination [2]. However, these liners are subjected to desiccation effect during long hours of exposure to the atmosphere thus causes shrinkage and eventually cracks failure [3].

Hydraulic conductivity is the most significant factor effecting soil liner performance. Liner are commonly composed of compacted soils and compaction characteristics consider as important role in determining the hydraulic conductivity [4]. This good compaction characteristic encourages the use of tropical residual soil as compacted clay liners (CCL) as a barrier not to only the economic application using local materials as CCL. Normally the hydraulic conductivity value for compacted liner must be less than or equal to 1 x 10^{-9} m/s [4-5]. Thus, more study is needed on the suitability use of bentonite (clay mineral) mixed with residual soil in order to determine the effectiveness of bentonite mixture on sedimentary residual soil. Therefore, it is useful for designing these types of engineered fill systems and to understand these mixtures as a purpose for compaction process and compaction energy that is used.

Hence the aim of this study was to evaluate the effectiveness of various percentage of bentonite content mixed with Salak Tinggi residual soil on the physical properties and engineering properties in hydraulic conductivity. This paper particularly reports the result finding on physical properties and results of hydraulic investigation on compacted Salak Tinggi residual soil mixed with bentonite from the several testing.

2. Materials

2.1. Salak Tinggi residual soil

Disturbed soil samples of yellowish residual soil Grade IV used in this study were derived from sedimentary residual soil and was collected in Salak Tinggi, Selangor, Malaysia. This soil samples were named as Salak Tinggi residual soil. To minimize the organic matter content, the soil was taken at 1.5 m to 2.5 m below from ground surface. Based on the geological map obtained from Minerals and Geoscience Department Malaysia [6], the Salak Tinggi area classified as sedimentary soil derived from phyllite, schist and slate: limestone and sandstone prominent. The yellowish-brown colours of Salak Tinggi soil were due to the changes on the mineral composition from the erosion of the top layer of parent rock. Seepage of the soluble minerals in the eroded materials deep underneath surface layer making the insoluble Fe and Al ions remains on the top. These metallic oxides create a new soil and gave the brownish colour. The physical properties were investigated guided from BS 1377: Part 2: 1990 and the result shown in Table 1. From the result, Salak Tinggi soil considered as strong acidic soil due to the average of *pH* value is 3.5 which are common in tropical climates [7]. It shows the Salak Tinggi soil sample considered as coarse soil with the major size of sand 69.2% and silt size 20.9% and clay size 9.9%. Meanwhile the plastic limit and liquid limit are 16% and 29% respectively. Based from the properties result, Salak Tinggi residual soil classified as Silty SAND (Low Plasticity, ML).

Table 1. Formatting sections, subsections and subsubsections.

Properties	Values
Depth (m)	1.5 – 2.5
Colour	Yellowish
Natural Moisture Content (%)	20.2
pH	3.5
Specific Gravity, (*Gs*)	2.67
Liquid Limit, *LL* (%)	29
Plastic Limit, *PL* (%)	16
Plasticity Index, *PI* (%)	13
Hydraulic Conductivity, *k* (m/s)	1.005 x 10^{-9}
Gravel (%)	0
Sand (%)	69.2
Silt (%)	20.9

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Clay (%)	9.9
Classification	Very Silty SAND of Low Plasticity, ML

2.2. Bentonite
The sodium bentonite used in this study was in grey powder provided from the main supplier. Scientifically, bentonite is a term used to name smectic clay in its sedimentary form and has high content of clay mineral (usually montmorillonite). This clay mineral capable of swelling during uptake of water, has large specific surface area, excellent plasticity, and has low hydraulic conductivity [8]. Due to these characteristics, bentonite has a major role in industrial, environmental, and civil engineering activities that require sealants, absorbents, and hydraulic barriers. The laboratories testing result shown in Table 2 for the bentonite properties conducted based on BS 1377: Part 2: 1990. The results show the bentonite considered as a strong alkaline due to the high of *pH* value about 9.6 and has extremely of high plasticity index.

Table 2. Physical properties for bentonite [9].

Properties	Values
Colour	Grey powder
pH	9.62
Specific Gravity, (*Gs*)	2.14
Liquid Limit, *LL* (%)	419
Plastic Limit, *PL* (%)	190
Plasticity Index, *PI* (%)	229

3. Samples preparation and laboratories testing
The Salak Tinggi residual soil sample was mixed with bentonite and was prepared manually. Four (4) different samples were prepared based on the different percentage of bentonite as shown in Table 3. The samples of natural Salak Tinggi soil without mixed of bentonite consider as control samples. The air-dried soil samples passing 20 mm was mixed with different percentage of bentonite at 5%, 10% and 15% by dry weight of soil. After that, the mixture samples were moistened with distilled water to allow all mixture blended for overall mixed sample to get the homogenous mixed and the samples were allowed to air dried at least for 24 hour prior for properties testing and compaction testing [9].

Table 3. Details of mixed sample.

Sample	Bentonite (%)	Symbol
Soil	0	S
Soil + 5B	5	S+5B
Soil + 10B	10	S+10B
Soil + 15B	15	S+15B

All entire prepared mixed samples were used to determine the physical properties such as *pH*, Atterberg limit, size distribution and linear shrinkage. All physical testing is based from BS 1377: Part 2: 1990. Meanwhile, standard proctor compaction testing was done on soil samples to determine the optimum moisture content (OMC) and maximum dry density (MDD) based from BS1377: Part 4:1990:3.3.

The mixed samples for permeability test were prepared and mixed thoroughly with distilled water at OMC value in order to get the homogenous mixture. After that samples were compacted using

IOP Conf. Series: Materials Science and Engineering **513** (2019) 012024 doi:10.1088/1757-899X/513/1/012024

standard compaction proctor test. Basically, the test specimens for permeability test proposed by BS 1377: Part 6: 1990 is about 100 mm diameter and 100 mm high, although specimens of other dimensions from 38 mm diameter upwards may be used. Therefore, the approaches taken in this study were using the sample about 75 mm in diameter and 35 mm in height. It was obtained that the longer sample was used, the longer it takes to stabilize. This approach was considered from previous researchers [10-11].

The permeability testing was conducted on all entire mixed soil samples to determine the hydraulic conductivity value; *k*. Samples for permeability test was compacted at MDD condition using standard compaction test. Permeability test was carried out using Triaxial consolidation test in a hydraulic consolidation cell as stated in BS1377: Part 6:1990. This method is suitable for soils with low and intermediate permeability and produced hydraulic conductivity at fast measurement rates for soil containing fine grain soils. This method covered the measurement of the coefficient of permeability at laterally confined specimen of soil under a known vertical effective stress, and under the application of a back pressure. The hydraulic conductivity value *k* is the rate of discharge of water under laminar flow conditions through a unit cross sectional area of porous medium under a unit hydraulic gradient and standard temperature conditions. The effective stress of 100 kPa were applied to samples during the permeability test and the volume of water passing through the mixed soil samples in a known time, and under a constant hydraulic gradient were measured.

4. Results and discussion

The soil engineering characteristics are depending on the particle size distribution. Table 4 shows the summarize tabulation grading of particles size distribution result for Salak Tinggi residual soil and mixed samples of Salak Tinggi Residual with bentonite. From the results, it shows an increment of fine grain particles along with reduction on the coarse grain size after addition of bentonite from 5% to 15%. It can be seen, addition of bentonite was increased clay size content and alter to reduce the silt size and sand size content. This due to the bentonite has high content of clay mineral of montmorillonite. This shows mixed samples considered as good liner because a good soil liner should have at least 30% of fine grain content and 15% of clay content [12].

Table 4. Summarize of the tabulation of grading size results for Salak Tinggi residual mixed bentonite.

Sample	Coarse grain		Fine grain		Classification (from BSCS)
	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	
Soil	0	69.14	20.92	9.94	Very Silty SAND
Soil + 5B	0	63.63	17.93	18.44	Sandy CLAY
Soil + 10B	0	61.42	15.59	22.99	Sandy CLAY
Soil + 15B	0	59.33	16.11	24.56	Sandy CLAY

Figure 1 shows that a mixture of bentonite with Salak Tinggi residual soil were affected to alter the pH value from acidic to alkaline condition after addition of 5%, 10% and 15% bentonite from pH of 8.21, 8.64 to 8.96 respectively. In acid condition (pH < 7) the soil particle tend to flock particle and flock each other in a random orientation produced a flocculated structure. These flocculants structure possesses a high void ratio and will result a high on hydraulic conductivity value [12-14]. Consequence on soil with pH > 7 produced the low of hydraulic conductivity value.

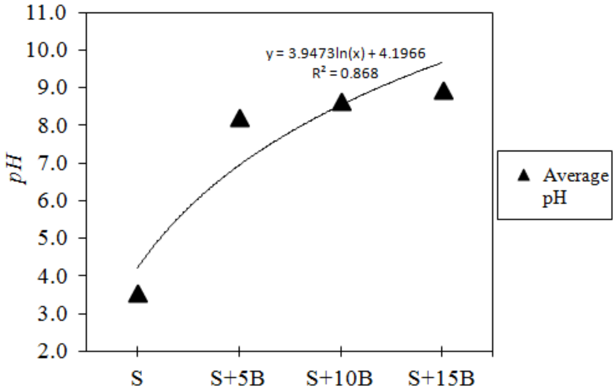

Figure 1. The *pH* result of Salak Tinggi Residual mixed bentonite.

Figure 2 shows the consequence of addition various percentage bentonite with Salak Tinggi residual soil on the liquid limit (*LL*), plastic limit (*PL*) and plastic index (*PI*). It was found that, with increase of bentonite percentage used in soil was increased the *LL* and as well as the *PL*. These also were resulting in increment of *PI* value of mixed samples. This was proved that bentonite action was changed the characteristics of soil properties. From the results, it shows that the mixed samples classification was changed the soil classification to low plasticity after addition 5% bentonite and change to Intermediate plasticity after addition of 10% bentonite and change to high of plasticity after addition of 15% bentonite. The increasing trend of *PI* index for mixed soil samples indicates the increase of clay portion in mixture soil and having a higher of surface activity. The plasticity index of soil is directly related to the mineralogy of the soil. Soil that produces high *LL* and *PI* generally contains more clay minerals and typically presents a low hydraulic conductivity [4]. It indicates that the *LL* and *PI* of mixed soil are primarily controlled by its clay content from bentonite. The suitable requirement for liner materials when the LL>20 and PI>7[12-14], meanwhile the low of shrinkage can be expected if the PI<35 [12-14]. Therefore, the results shows the addition of bentonite 5%, 10% and 15% were fulfil the requirement as liner materials.

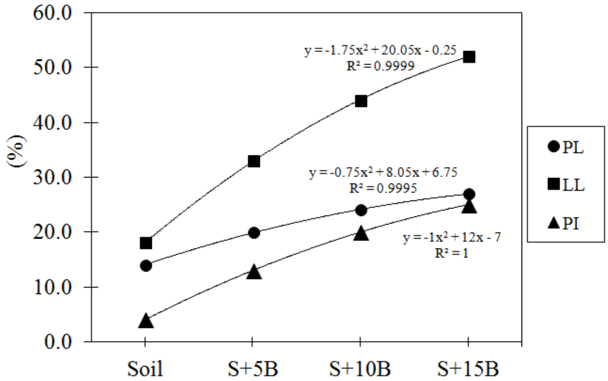

Figure 2. The consistency limit result of Salak Tinggi residual soil mixed bentonite.

Figure 3 shows the linear shrinkage result for mixed soil samples with bentonite. It shows that the linear shrinkage of the mixed soil sample increase as the percentage of bentonite increase and it shows a significant of increment on linear shrinkage increasing with the increasing percentage of bentonite. This indicates that the soil mixed bentonite has a higher change in volume. However, soil with a limit of linear shrinkage of less than 12% indicates the ability of a small change in volume [12-14]. Shrinkage of the soil increase due to high plasticity index of bentonite and the significant increase of plasticity index and linear shrinkage limit over 15% bentonite is due to the high water absorption capacity of bentonite. Besides that, shrinkage behaviour significantly affected by fine particles consisted in the soil distribution rather than by the plasticity characteristics and fine particles in the soil were a better indicator of shrinkage than plasticity characteristics. The high percentage of fine particles that consist in bentonite and the ability of soil to absorb water increased as the clay content (bentonite) were increased.

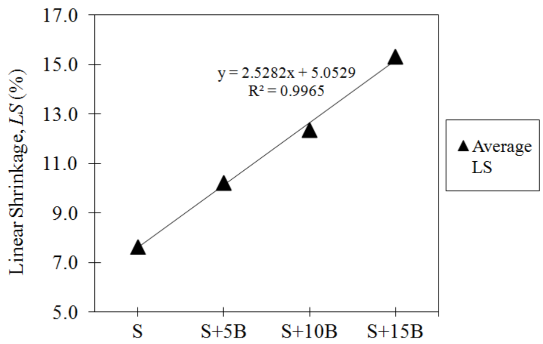

Figure 3. The linear shrinkage result of Salak Tinggi residual soil mixed bentonite.

Figure 4 show the compaction curve result for Salak Tinggi residual soil mixed with different percentage of bentonite at standard compaction. The different percentage of bentonite used was affecting the maximum dry density (MDD) and optimum moisture content (OMC) result.

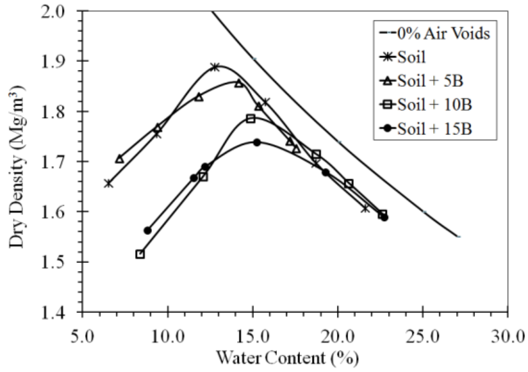

Figure 4. Compaction curves for Salak Tinggi residual soil mixed with different percentage of bentonite at standard compaction.

Figure 5 and Figure 6 shows the result for MDD and OMC from standard proctor compaction at different percentage of bentonite. It shows an increment OMC value and at once decrement of MDD after addition of bentonite. It can be seen the MDD value for natural Salak Tinggi soil is 1.89 kN/m^3 and dropped down to 1.86 kN/m^3, 1.79 kN/m^3 and 1.74 kN/m^3 after the addition of 5%, 10% and 15% bentonite respectively due to the increment of bentonite content. Otherwise the OMC for natural Salak Tinggi soil is 13% and increased to 14%, 15% and 15.5% as the bentonite content were increased from 5%, 10% and 15% respectively. The reduction in MDD with increasing of bentonite is due to the high swelling of bentonite characteristics that forms a gel around the soil particles. These causes increment in effective size of particle and at once increase void volume and thus decreased dry unit weight. Meanwhile the increase of OMC was related to require more moisture for hydration reaction comes from the increment of fine grains size [12-15].

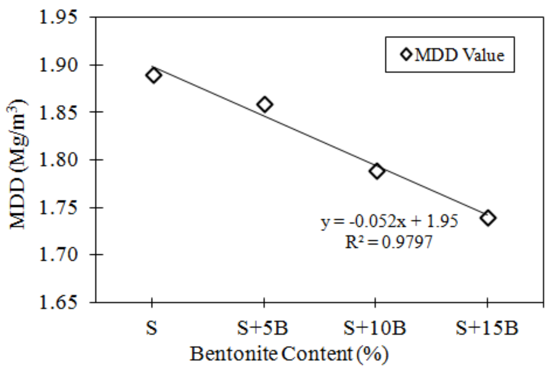

Figure 5. The MDD value at different percentage of bentonite mixture at standard compaction.

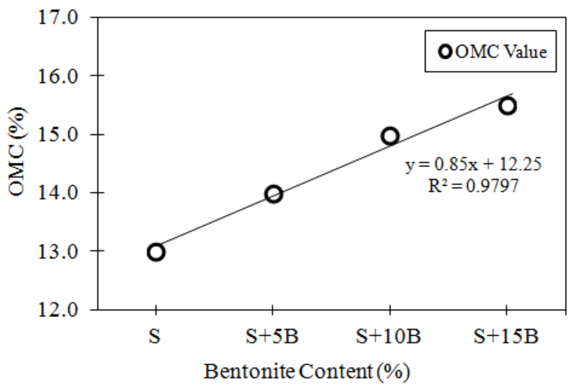

Figure 6. The OMC value at different percentage of bentonite mixture at standard compaction.

Figure 7 shows the result of hydraulic conductivity value for Salak Tinggi residual soil mixed with different percentage of bentonite at standard compaction. It is clearly demonstrate that the increase in bentonite content considerably reduced the hydraulic conductivity value at the highest confining stress of 100 kPa. It shows the hydraulic conductivity value for natural Salak Tinggi soil is 1.005 x 10^{-9} m/s and dropped down to 2.430 x 10^{-10} m/s, 9.342 x 10^{-11} m/s and 5.111 x 10^{-12} m/s after the addition of 5%, 10% and 15% bentonite respectively. It shows that soils compacted at OMC tend to have a lower hydraulic conductivity due to the increasing water content may resulted increased ability to break down clay aggregate and eliminate inter-aggregates pores [16-17]. In addition, increasing water content resulted in orientation of clay particles and producing a large water film around particles which causes swelling of clay and at once reducing the inter particles pores together resulting in low of hydraulic conductivity [16-18].

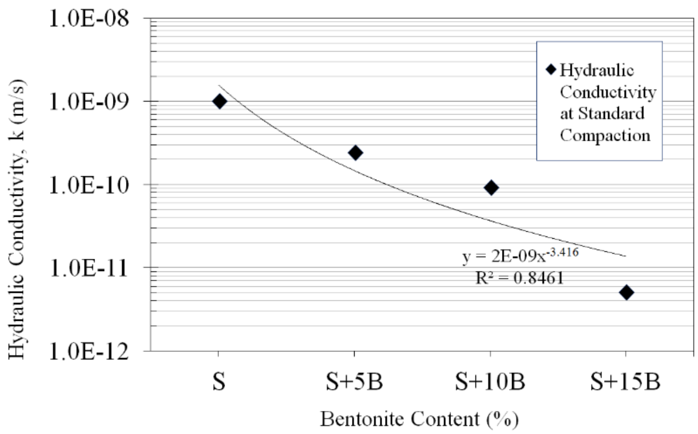

Figure 7. The effect of bentonite percentages on the hydraulic conductivity value, k at MDD conditions for standard proctor compaction.

5. Conclusion

Some basic characteristics of Salak Tinggi residual soil mixed bentonite have been studied from this study for the purposes as potential use as liner material. The physical properties, compaction and hydraulic conductivity were measured. It can be concluded that the addition of bentonite was resulted in changes in physical properties. It shows and increment of *pH*, plastic index, liquid limit, plasticity index, linear shrinkage and clay fraction content. It also changed the soil classification from clay low plasticity to clay high plasticity for addition bentonite 5% to 15% respectively. The compaction result shows the reduction of MDD and at the same time increase the OMC from addition of bentonite in line with increment of LL and PI. From this study, the suitable percentage of bentonite were determined in aout 5% to be used as mixture to the Salak Tinggi residual soil to produce the suitable physical properties for soil liner with suitable hydraulic conductivity value at standard compaction. However, it shows hydraulic conductivity value reduced by mixing with higher content of bentonite at standard compaction energy.

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References
[1] Taha M R and Kabir M H 2005 Tropical residual soil as compacted soil liners Environmental Geology **47**(3) 375–381.
[2] Faizal M, Tajul B, Ir B, Rashid A, Othman B, Fairus M and Aman B. 2006 Assessment on Physico-Chemical Properties for Granite Residual Soil as Landfill Liner Material at Batu Pahat, Johor, Malaysia. Technology and Innovation for Sustainable Development Conference, (January), 282–285
[3] Yesiller N, Miller C J, Inci G, and Yaldo K 2000. Desiccation and cracking behavior of three compacted landfill liner soils. Engineering Geology, **57**(1), 105-121
[4] Benson C H, Daniel D E and Boutwell G P 1999 Field performance of compacted clay liners. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. No. **5**, pp. 390-403.
[5] Benson C H, Daniel D E and Boutwell G P 1999 Field performance of compacted clay liners. Journal of Geotechnical and Geoenvironmental Engineering, ASCE, Vol. No. **5**, pp. 390-403.
[6] Minerals and Geoscience Department Malaysia Updated: 2012 Geological Map of Peninsular Malaysia based on the 8th edition Geological Map in 1985.
[7] Singh H, Huat B K, Sew G and Ali F 2004. Origin, formation and occurrence of tropical residual soils. In S. Gue and F. Ali (Eds.) Tropical Residual Soils Engineering. London: Taylor and Francis Group.
[8] Liu Y, Gates WP and Bouazza A 2013 Acid induced degradation of the bentonite component used in geosynthetic clay liners Geotextiles and Geomembranes Volume **36** (2013), pg 71 – 80.
[9] Norazlan Khalid and Mazidah Mukri 2017 Compaction Characteristics on Dengkil Residual Soil Mixed Bentonite Electronic Journal of Geotechnical Engineering, Vol. **22** (Bund. 2): 605-612
[10] Daniel D E and Benson C H 1990 Water content-density criteria for compacted soil liners Journal Geotech.Eng. ASCE 116 (GT12): 1811-1830
[11] Daniel D E and Liljestrand H M 1984 Effect of landfill leachates on natural liner systems. Report GR83-6, Geotechnical Engineering Centre, University of Texas, Austin.
[12] Benson C H, Zhai H and Wang X 1994 Estimating hydraulic conductivity of compacted clay liners. J Geotech Engrg ASCE 120(2):366–387.
[13] Daniel D E 1993a Clay Liners In Geotechnical Practice for Waste Disposal, (ed. David E. Daniel) Chapman and Hall, London, UK, pp 137-163.
[14] Daniel D E and Benson C H 1990 Water content density criteria for compacted soil liners.Journal Geotech. Eng. ASCE. 116 (12): 1811-1830.
[15] Mitchell J K and Soga K 2005 Fundamentals of Soil Behaviour. 3rd Edition. John Wiley and Sons Inc.
[16] Garcia-Bengochea I, Lovell C and Altschaeffl A 1979 Pore distribution and permeability of silty clays. J Geotech Eng ASCE 105(7):839–856.
[17] Osinubi K J and Nwaiwu C M O 2006 Hydraulic Conductivity of Compacted Lateritic Soil J. Geotechnical and Geoenvironmental Engineering, ASCE, Vol. **131**, No. 8, 1034 – 1041.

[18] Amadi A A, Afolayan J O and Osinubi K J 2014 Sensitivity Analysis of the Hydraulic Conductivity of Compacted Laterirtic Soil and Bentonite Composite. Geo-Congress 2014 Tehcnical Paper, GSP 234, ASCE, 921 – 930.