

# Geotechnical Properties of Salak Tinggi Residual Soil-Bentonite Mixture as Liner

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## ABSTRACT

*This paper intends to present an experimental study on the effectiveness of using bentonite mixed with originating sedimentary residual soil as a liner. In order to investigate the effectiveness of soil-bentonite mixture, several tests were performed on Salak Tinggi sedimentary residual soil mixed with different percentage of bentonite content such as 5%, 10% and 15%. The laboratory testing was performed on the mixed sample consist of physical properties of the soil such as: pH, plastic limit (PL), liquid limit (LL), plasticity index (PI), linear shrinkage (LS) and specific gravity (SG). Meanwhile, the compaction testing was performed such as British Standard Light (BSL) and British Standard Heavy (BSH). The compaction test was conducted to determine the maximum dry density (MDD) and optimum moisture content (OMC) at two different compaction energies. The result showed that the addition of bentonite on the Salak Tinggi residual soil can change and improve the physical properties of the results. Moreover, the results of compaction show a decrease in the MDD value for any increase in the percentage of bentonite mixture at all energies. However, MDD value increases with increasing of compaction energy used in soil-bentonite mixture. All these changes improved the performance of residual soil use as liner purposes.*

**Keywords:** *Bentonite; Residual Soil; Soil Liner; Compaction Test; Moisture Content.*

## Introduction

Residual soils were formed from weathering of rocks and deposited above the parent rocks. Commonly, residual soils are formed from the continuous geological process on the earth's surface which comprises of the degradation of parent igneous, sedimentary or metamorphic rock [17]. The factors that influence the character of the residual soils are parent materials, climate, drainage, topography and ages. The characteristics of residual soil are depending on their parent rock and vary along the depth towards the weathered rock [12].

The issues for residual soils in tropics area are not feasible as Compacted Clay Liner (CCL) application due to varieties in characteristics. In current practice, there are different kind of clay liners used during the construction of landfill areas such as inorganic clays or clayey soils due to low hydraulic conductivity. Therefore, bentonite is normally mixed with local soil if the natural clay or clayey soils are not available. Furthermore, it is also important to know the compaction characteristics mixtures of residual soil-bentonite as liners conditions. The compaction characteristic of liner plays an important role in determining the hydraulic conductivity. Low hydraulic conductivity is achieved when the soil is compacted at high, dry density and a water content wet of optimum. Normally, the hydraulic conductivity value for compacted liner must be less than or equal to  $1 \times 10^{-9}$  m/s. Thus, more study is needed on the suitability use of bentonite mixed with residual soil in order to determine the effectiveness of a bentonite mixture of sedimentary residual soil. 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 used [5,6,7,9].

In Malaysia, Compacted Clay Liners (CCL) and Geo-synthetic Clay Liners (GCL) are commonly used as a protective layer on residual soil surface to prevent groundwater contamination [11]. These liners are subject to desiccation effect during long hours of exposure to the atmosphere which causes shrinkage and eventually cracks of the clay liner. Likewise, clay liners may fail on serving its purposes if proper study did not monitor or conducted according to the standard procedure.

Therefore, the main purpose of this study is to evaluate the effectiveness and optimize the amount, percentage of bentonite content which can be mixed with Salak Tinggi sedimentary residual soil. This study also to determine the correlation between percentage of bentonite with specific gravity, pH, linear shrinkage, consistency limit, dry density, maximum dry density and optimum moisture content.

## **Research Methodology**

### **Testing Method**

This study focuses on an experimental work conducted in several laboratories testing to show the effectiveness of using bentonite mixed with residual soil. The soil samples which sieve passing 20 mm were prepared and mixed with 5%, 10% and 15% percentage of bentonite as replacement of the dry weight of soil. A total number of samples were prepared in the laboratory with mixed of soil together with different percentage of bentonite. Table 1 shows the control sample with 0% bentonite (S), soil with 5% bentonite (S+5B), soil with 10% bentonite (S+10B) and soil with 15% bentonite (S+15B). Then, the mixed samples were moistened using distilled water and blended together using soil blender. All mixtures were processes physically inn order to get the homogenous mixture and the allowed the sample to dry at least 24-hour prior for physical testing and compaction testing [16].

Table 1: Details proportion of the mixed samples.

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

All the mixtures samples were prepared properly in order to determine the physical and engineering properties such as pH, liquid limit, plastic limit, plasticity index, linear shrinkage, specific gravity and compaction characteristics. The testing of soil samples for physical properties were conducted based from BS 1377: Part 2: 1990 [8]. In order to get the precise result during the experimental work, the laboratories testing was repeated at least three times for each sample. Meanwhile, two different compaction characteristics from different energy were used such as British Standard Light (BSL) compaction and British Standard Heavy (BSH) compaction. All the compaction tests were used to determine the optimum moisture content (OMC) and maximum dry density (MDD) of the mixed soil. The BSL and BSH compactions testing were accordance to the Standard Proctor compactions and British Standard Modified based from (BS1377: Part 4:1990:3.3 and BS1377: Part 4:1990:3.5), respectively [8]. The results of BSL and BSH compaction were produced with the values of 606 kNm/m<sup>3</sup> and 2724 kNm/m<sup>3</sup> energy, respectively.

## Materials

The sedimentary soil Grade IV sample was taken from Salak Tinggi, Selangor, Malaysia and this kind of soil sample was used in many geotechnical engineering works in Malaysia. The site location was selected based on geological mapping from Minerals and Geosciences Department Malaysia [14]. The sampling area was categorized as sedimentary soil which derived from phyllite, schist, slate, limestone and sandstone prominent. The yellowish colour of soil which collected from Salak Tinggi was due to changes of mineral composition from the erosion on the top layer of parent rock. Seepage of the soluble minerals in the eroded materials deep underneath surface layer making the insoluble ferum (Fe) and aluminium (Al) ions remains at the top of the soil. These metallic oxides create a new soil and gave the brownish colour. Thus, Salak Tinggi soil is considered as strong acidic soil with average value of  $pH$  is 3.54. The Salak Tinggi residual soil samples had been tested for physical properties in accordance to BS 1377: Part 2: 1990 [8]. Table 2 shows the physical and engineering properties of Salak Tinggi residual soil. The result shows that the average specific gravity for Salak Tinggi residual soil is 2.67 and these values show the similarities when compared with previous studies of sedimentary residual soil [2,18,19]. The residual soil specific gravity values are varies at each location depending on the mineralogy of soil and the history of weathering at any specific site. Therefore, it can be concluded that Salak Tinggi residual soil is classified as Very Clayey Sand (SCL) with clay of low plasticity.

Table 2: Physical properties of Salak Tinggi residual soil.

Physical Properties	Range of Values
Depth (m)	1.5 – 2.5
Colour	Yellowish brown
Natural Moisture Content (%)	17.1 – 18.3
$pH$	3.34 – 3.62
Specific Gravity, ( $G_s$ )	2.62 – 2.69
Liquid Limit, $LL$ (%)	29.2 – 33.4
Plastic Limit, $PL$ (%)	16.0 – 17.2
Plasticity Index, $PI$ (%)	13.2 – 16.3
Liner Shrinkage, $LS$ (%)	7.19 – 7.91
Gravel (%)	0
Sand (%)	66.8 – 71.3
Silt (%)	19.1 – 22.3
Clay (%)	9.6 – 10.3
Classification	Very Clayey Sand (Clay of Low Plasticity),

The bentonite used in this study is categorized as sodium bentonite with brownish grey powder which had provided by main supplier. The bentonite sample was tested for the physical properties in accordance to BS 1377: Part 2:1990. Table 3 shows the results of physical properties of bentonite. The result highlights that the bentonite sample is categorized as light materials because it has very low density and considered as a strong alkaline material due to its high value of pH 9.6 and has extremely high value of plasticity index.

Table 3: Physical properties of bentonite.

Physical Properties	Range of Values
Colour	Brownish grey
<i>pH</i>	9.6 – 9.7
Density	1.02 – 1.14
Viscosity	45 - 55
Specific Gravity, ( <i>G<sub>s</sub></i> )	2.14 – 2.21
Liquid Limit, <i>LL</i> (%)	343 - 419
Plastic Limit, <i>PL</i> (%)	98 - 193
Plasticity Index, <i>PI</i> (%)	155 - 331

## Results and Discussions

Figure 1 shows the relationship between specific gravity (*G<sub>s</sub>*) and different percentage of soil mixture samples. It shows the specific gravity value of mixed samples increase with additional percentage of bentonite. It is a positive linear correlation exists between them with high coefficients of determinations ( $R_2=0.9539$ ). Generally, the value of specific gravity slightly increase from 2.71, 2.74 and 2.81 with respect of 5%, 10% and 15% of bentonite, respectively. It shows that the bentonite is a form of clay mineral which can influence directly the clay content mixture and resulting in high amount of void ratio by increasing the specific gravity value.

Obviously, Salak Tinggi residual soil has strong acidity with average *pH* value of 3.54 as shown in Table 2. However, the *pH* of Salak Tinggi residual change to alkaline condition after mixed with different percentage bentonite. In average, it shows the *pH* value is increases from 8.21, 8.63, 8.96 after additional of 5%, 10% and 15% bentonite, respectively. The result shows that the *pH* value had change from acidic to alkaline condition with strong relationship between them. The bentonite with a positive linear correlation has high coefficients of determination ( $R_2=0.9962$ ). These results indicate that under the condition of low pH value (acidic condition), the soil particles tend to form a bunch and flocculation structure. This condition provides a high void ratio and at the same time

produce a high of hydraulic conductivity value. However, soil in alkaline condition is not easy to form a bunch and flocculation structure due to the deficiency ability of cation adsorption capacity caused by the presence of montmorillonite minerals in bentonite.

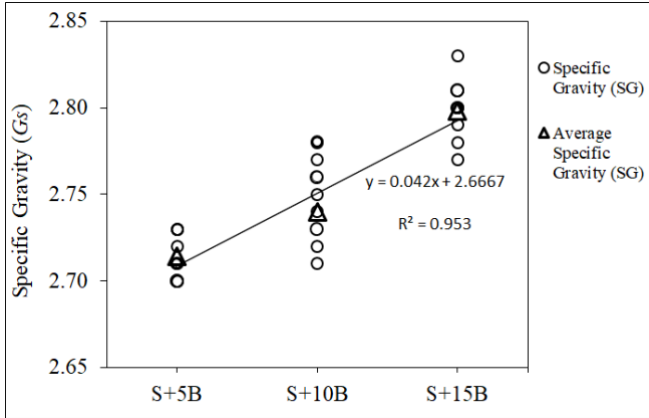


Figure 1: Specific gravity versus different percentage of soil mixture.

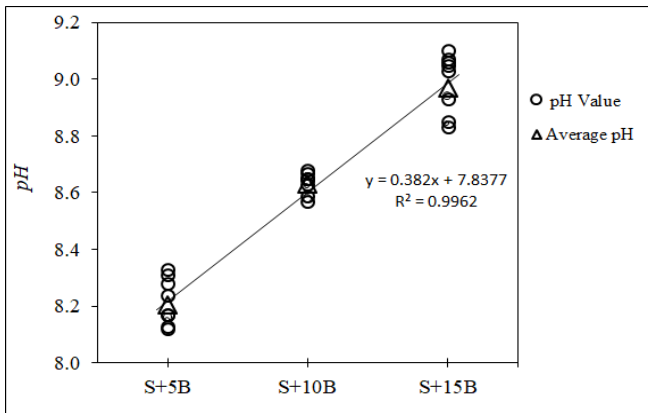


Figure 2: Value of pH versus different percentage of soil mixture.

Figure 3 shows the linear shrinkage (*LS*) of the sample increases as the percentage of bentonite increase. Generally, an average value of *LS* result shows a significant of linear shrinkage increasing trend from 10.2%, 12.4% and 15.3% with the increasing percentage of bentonite for 5%, 10% and 15%, respectively. It is clearly shows that linear correlation with high coefficient determinations ( $R_2=0.9917$ ). This indicates that the soil mixed

bentonite has high changes in volume. Soil with a limit of linear shrinkage of less than 12% indicates the ability of a small change in volume [13]. The linear shrinkage of soil was increased due to high plasticity index properties of bentonite. The significant increase of plasticity index and linear shrinkage limit over than 15% bentonite is due to the high water absorption capacity of bentonite [4].

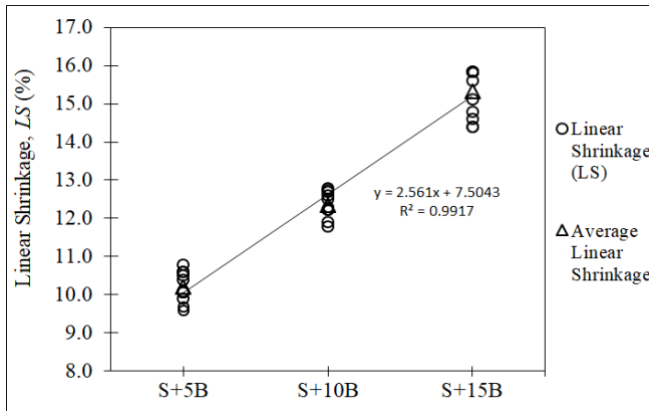


Figure 3: Linear shrinkage (*LS*) versus different percentage of soil mixture.

The consequence of additional different percentage bentonite with residual soil on the liquid limit (*LL*), plastic limit (*PL*) and plastic index (*PI*) are shown in Figure 4. Generally, the result shows the increment for all consistency limit for *LL*, *PL* and *PI* corresponds with increase of percentage addition of bentonite with residual soil. Generally, high plasticity soils have low permeability. However, soil with a very high plasticity becomes sticky when it is wet and hard to work on the site. Even the shrinkage is easily occurred if it is more than 30%. However, the *PI* value for this sample is not too high and indicates it has the appropriate plasticity properties to minimize the value of the conductivity in addition to the large shrinkage. Normally the higher of *LL* and *PI* are indicating the greater of clay percentage in soil and having a higher of surface activity. Therefore the increasing trend of *PI* index for bentonite mix with residual soil indicates the increase of clay portion in mixture soil [1]. At once the increment in *PI* and *LL* showing that the mixed residual soil contains a great quantity of clay particle and indirectly influenced to minimize the hydraulic conductivity value. Therefore the addition of 5%, 10% and 15% bentonite with and average *LL* value of 32%, 44% and 57% respectively are suitable to be used as soil liner due to the *LL* exceed 20%. From the consistency limit result, it shows the strong linear correlation by high coefficients of determination between percentage

bentonite and PL, LL and PI about  $R_2=0.9394$ ,  $R_2=0.9979$  and  $R_2=1$  respectively. It indicates that the LL and PI of mixed soil controlled by its clay content from bentonite. Therefore, the consistency limit result were fulfilled the suitable requirement for liner materials with the  $LL > 20$  and  $PI > 7$  [5,6,7], meanwhile the low of shrinkage can be expected if the  $PI < 35$  [9].

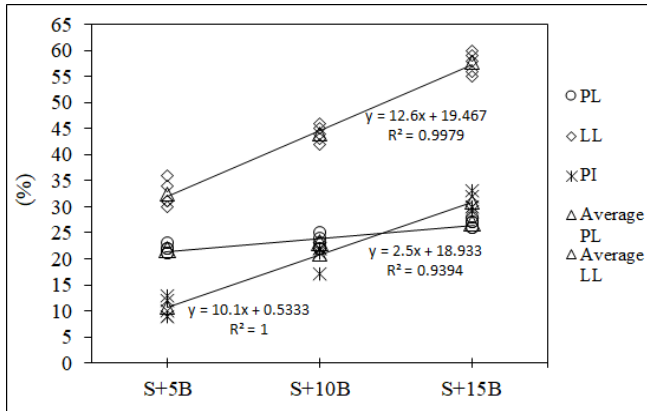


Figure 4: Consistency limit versus different percentage of soil mixture.

Figure 5 shows a graphically a compaction curve for Salak Tinggi residual soil mixed bentonite. The result shows an increment of curvature compaction curve and were resulted the increment of MDD value toward the increment of compaction energy from BSL compaction to BSH compaction for energy 606 kNm/m<sup>3</sup> and 2724 kNm/m<sup>3</sup>, respectively. Otherwise, the increment percentages of bentonite were given the decrement of MDD towards increase of OMC. It clearly shows that the dry unit weight and the optimum moisture content were affected by the compaction energy applied to the soil sample whether the soil was mixed or not with addition of bentonite [16].



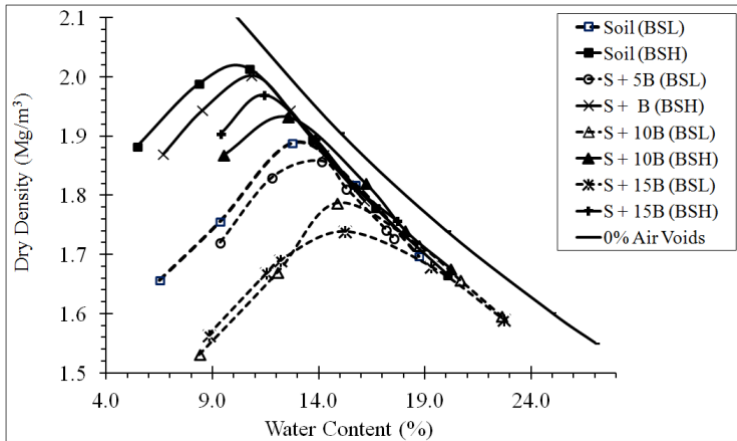


Figure 5: Compaction curves for Salak Tinggi residual soil mixed with different percentage of bentonite at different level of compaction energies.

Figure 6 and 7 show the summarization on the effect of compaction energy at different percentage of bentonite mixture to the soil on the MDD and OMC value. Figure 6 shows the MDD were decreased with increment percentage of bentonite. Though, the MDD value increase with increment of compaction energy from BSL to BSH. Meanwhile, Figure 7 shows the contradicts result as compared to Figure 6. It shows the OMC value decrease with the increment in compaction energy from BSH to BSL for each mixed samples. For compaction, the critical moisture content occurs at the peak of the curve. A lot of factors contribute to the critical moisture content of soil including soil texture and organic content [15]. The increase of MDD value are due to the higher of compaction energy give in a more parallel orientation of the clay particle which gives a more dispersed structure. The particles of soil become closer and higher unit weight of compaction result [10]. Meanwhile, on the dry part of optimum, the moisture content has a tendency to diffuse the soil under dominant repulsive force where clay platelets are aligning in parallel orientation and giving the increment in OMC value.

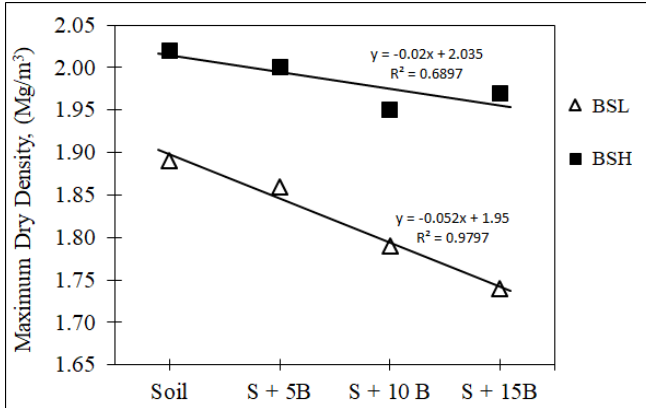


Figure 6: Comparison of MDD versus mixed samples at different compaction effort.

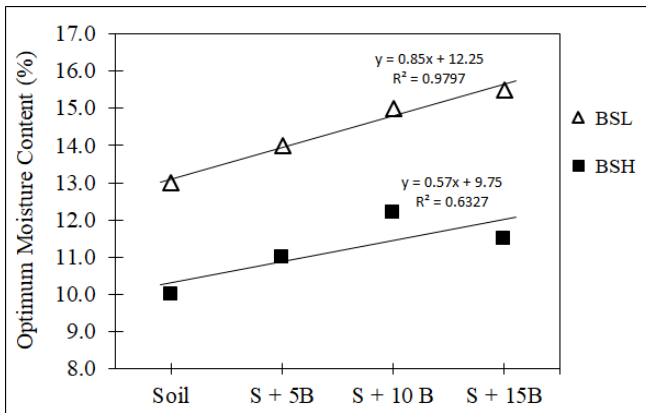


Figure 7: Comparison of OMC versus mixed samples at different compaction.

## Conclusions

This study attempts to illuminate the effect of using different percentage of bentonite mixed with Salak Tinggi residual soil on physical properties and compaction characteristics. It can be concluded that by adding small percentage of bentonite in Salak Tinggi residual soils were resulted in changes and increment of physical properties such as  $pH$ , plastic index, liquid limit, plasticity index, linear shrinkage and specific gravity. Meanwhile, it

also resulted in MDD and OMC value at different energies of compaction at different series percentage of bentonite. It shows, the MDD result increase with increasing of compaction energy once reducing the OMC even though with the increment of bentonite. In fact, the higher bentonite content will yield to the lower of MDD and higher of OMC. The increment percentage of bentonite mixture requires a high energy of compaction to achieve the MDD. Therefore from the laboratories result, it shows that the use of bentonite mixed with residual soil might significantly change the properties of soil and could make them potential uses as compacted liner. All these changes in properties may improve the performance of residual soil use as liner purposes especially in reducing the hydraulic conductivity conditions.

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### **References**

- [1] Amadi, A.A., Afolayan, J.O. and Osinubi, K.J. “Sensitivity Analysis of the Hydraulic Conductivity of Compacted Lateritic Soil and Bentonite Composite” *Geo-Congress 2014 Technical Paper*, GSP 234, ASCE, 921 – 930, 2014.
- [2] Aminaton, M., Fauziah, K., and Nizar, K. “Mineralogy and Microstructure of Residual Soils of Peninsular Malaysia”, *Proceeding of the Seminar on Construction*, pp. 397–407, 2001a.
- [3] Aminaton, M., Fauziah, K., & Nizar, K. “The Chemical Compositions of Granitic Soil from Southern and Eastern Regions of Peninsular Malaysia” (6th Region). Kuching, 2001b.
- [4] Basha, E. A., Hashim, R., Mahmud, H. B., and Muntohar, A. S. “Stabilization of residual soil with rice husk ash and cement” *Construction and Building Materials*, 19(6), 448–453, 2005.
- [5] Benson, C. H., Daniel, D. E. & Boutwell, G. P. “ Field performance of compacted clay liners” *Journal of Geotechnical and Geo-environmental Engineering*, ASCE, 95(5) pp. 390-403, 1999.
- [6] Benson, C.H. ang Trast, J.M. “Hydraulic conductivity of thirteen compacted clays” *Clays Clay Min* 43(6):669–681, 1995.

- [7] Benson, C.H., Zhai, H., and Wang, X. "Estimating hydraulic conductivity of compacted clay liners" *Journal Geotechnical Engineering*, ASCE 120(2):366–387, 1994.
- [8] BS 1377, Part 1–4; Methods of test for Soils for civil engineering purposes. *British Standards Institution*. London. UK, 1990.
- [9] Daniel, D.E., and Benson, C.H. "Water content-density criteria for compacted soil liners" *Journal Geotechnical Engineering*, ASCE 116 (GT12): 1811-1830, 1990.
- [10] Das, B. M. "Principles of Geotechnical Engineering", *Cengage Learning* (7th ed., Vol. 53). Stamford: Cengage Learning, 2013.
- [11] Faizal, M., Tajul, B., Ir, B., Rashid, A., Othman, B., Fairus, M., and Aman, B. "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, 2006.
- [12] Huat, B. B., Toll, D. G., and Prasad, A. "Handbook of Tropical Residual Soils Engineering" *Boca Raton*: CRC Press, 2013.
- [13] Lutton, R.J., Regan, G.L., and Jones L.W. "Design and construction of covers for solid waste landfills" *Hazardous Waste Engineering Research Laboratory, Office of Research and Development, US Environmental Protection Agency*, 1979.
- [14] Minerals and Geoscience Department Malaysia, Geological Map of Peninsular Malaysia based on the 8th edition Geological Map in 1985, 2012.
- [15] Nik Nurul Syuhada Nik Ab Aziz, Mazidah Mukri, Soenita Hashim and Norazlan Khalid "Influence of Compaction Effort For Laterite Soil Mix With Geopolymer In Designing Soil Liner. *Electronic Journal of Geotechnical Engineering*, 20(Bund.22):12353-12364, 2015.
- [16] Norazlan Khalid and Mazidah Mukri "Compaction Characteristics on Dengkil Residual Soil Mixed Bentonite" *Electronic Journal of Geotechnical Engineering*, Vol. 22 (Bund. 2): 605-612, 2017.
- [17] Singh, H., Huat, B., Sew, G., and Ali, F. "Origin, formation and occurrence of tropical residual soils" In S. Gue & F. Ali (Eds.), *Tropical Residual Soils Engineering*, London: Taylor & Francis Group, 2004.
- [18] Taha, M.R., Kabir, M.H. "Tropical residual soil as compacted soil liners" *Proceedings of the 2nd International Conference on Advances in Soft Soil Engineering and Technology*, 2–4 July 2003, Putrajaya, Malaysia, pp 895–904, 2004
- [19] Taha, O.M.E. and Mohd, R.T. "Soil-water characteristic curves and hydraulic conductivity of nanomaterial-soil-bentonite mixtures" *Arab Journal Geosciences*, 9: 12, 2015.