Effect of compaction characteristics on hydraulic conductivity performance for sedimentary residual soil mixed bentonite as compacted liners

Norazlan Khalid¹, Mazidah Mukri¹, Faizah Kamarudin² and Abdul Halim Abdul Ghani³

¹Faculty of Civil Engineering, Universiti Teknologi MARA, Shah Alam, Malaysia
²Faculty of Civil Engineering Universiti Teknologi MARA, Pulau Pinang, Malaysia
³Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia
*Corresponding author: aln_kh82@yahoo.com

Abstract. This paper discusses on the compaction effect to the hydraulic conductivity performance for the sedimentary residual soil mixed bentonite. This mixture is proposed as a barrier material in landfill area and may possibly potential materials for use as compacted soil liners in landfills for leachate protection. A laboratories series was conducted to evaluate the effectiveness of compaction characteristics on sedimentary residual soil mixed with different percentage of bentonite (5%, 10% and 15%). The sedimentary residual soil sample was used in this study and was collected in sedimentary residual formation area in Salak Tinggi, Malaysia and named as Salak Tinggi soil. The mixed samples were compacted at three different compaction effort with different energy to determine the maximum dry density (MDD) and optimum moisture content (OMC). Then, the permeability test to determine the hydraulic conductivity (k) was conducted at MDD condition at every compaction effort at effective stress of 100 kPa. The results show that the MDD value were slightly low for the entire soil sample mixed with bentonite at all compaction energy level. Instead it shows all the three different compaction efforts applied to the mixed soil samples with bentonite yielded hydraulic conductivity less (k < 1x10⁻⁹ m/s). In fact, the increment of bentonite content also resulted in lower of MDD value and hydraulic conductivity value. However, MDD values were found to be higher for mixed soil when compacted with high compaction effort. The results of hydraulic conductivity tests demonstrated that hydraulic conductivity, k < 1x10⁻⁹ m/s can be achieved just by using lower compaction energy for the soil mix with bentonite. Instead it considered as suitable materials for liner due to the hydraulic requirement for soil barrier, k < 1x10⁻⁹ m/s. This finding show that compaction efforts play an important role for workability of the mixtures and significantly to be used as compacted of soil liner materials.

1. Introduction
Compacted soil liner has been used and served as engineer hydraulic barrier in waste containment facilities and made of naturally sand mixed with significant amount of clay. The barrier could not serve as soil liner if there is not enough amount of clay in the mix of soil liner which leads to infiltration of leachate from waste, which could pollute the environment and groundwater [1-2]. In order to prevent groundwater contamination, Compacted Clay Liners (CCL) and Geo-synthetic Clay Liners (GCL) are commonly used as a protective layer on residual soil surface especially in Malaysia [3].
Therefore, the major concern issues for residual soils in tropical climate area are not feasible as compacted clay liner application due to vary 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. Therefore bentonite was used to be mixed with local soil if natural clay or clayey soils are not available and it is important to know the compaction characteristics mixtures of residual soil-bentonite as liners conditions.

Since bentonite has large specific surface area, excellent plasticity and low hydraulic conductivity, these make bentonite is significance in industry and civil engineering activities requiring absorbent, hydraulic barrier and sealant [1]. Normally, original soils are mixed with significant amount of clay to form a soil liner, because clay helps to reduce hydraulic conductivity barrier and subsurface contamination [4].

These good compaction characteristic encourage the use of residual soil as compacted clay liners (CCL) as a barrier not to only the economic application using local materials as CCL. Other than compaction, hydraulic conductivity is the most important factor affecting soil performance. Engineered landfill for hydraulic conductivity value for compacted liner must be $k < 1 \times 10^{-9}$ m/s [5-6]. Therefore it is useful for designing these types of engineered fill systems and to have understanding of these mixtures as a purpose for compaction process and compaction energy that is used.

This study was to assess the effectiveness of compaction characteristics to the hydraulic conductivity performance of sedimentary residual soil mixed bentonite. This paper reports the result finding on the hydraulic conductivity value on the compacted Salak Tinggi sedimentary residual soil containing different bentonite content from different compaction effort.

2. Materials

2.1. Salak Tinggi sedimentary residual soil

Sedimentary residual soil was used broadly in many geotechnical engineering works in Malaysia and was chosen for this study. The yellowish residual soil Grade IV Soil samples was collected in Salak Tinggi, Selangor and named as Salak Tinggi residual soil. Salak Tinggi area was grouped as sedimentary soil derived from phyllite, schist and slate: limestone and sandstone prominent [7]. Table 1 shows the physical properties result for Salak Tinggi Residual in accordance to BS 1377: Part 2: 1990 [8]. 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 and 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 (Clay of Low Plasticity, SCL).

| Properties                        | Values          |
|-----------------------------------|-----------------|
| Depth (m)                         | 1.5 – 2.5       |
| Natural Moisture Content (%)       | 20.2            |
| $pH$                              | 3.5             |
| Specific Gravity, ($G_s$)         | 2.67            |
| Liquid Limit, $LL$ (%)            | 29              |
| Plastic Limit, $PL$ (%)           | 16              |
| Plasticity Index, $PI$ (%)        | 13              |
| Gravel (%)                        | 0               |
| Sand (%)                          | 69.2            |
| Silt (%)                          | 20.9            |
| Clay (%)                          | 9.9             |
2.2. Bentonite

The grey powder of sodium bentonite used in this study was provided from the main supplier and used to produce the mixture of Salak Tinggi soil-bentonite samples. The bentonite sample was tested for the properties according to BS 1377: Part 2: 1990 [8] and the result shown in Table 2. Scientifically, bentonite term is smectic clay in its sedimentary form and has high content of montmorillonite as a clay mineral. From the result, it can be seen 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 [9-10]. |
| --- | --- |
| Properties | Values |
| pH | 9.62 |
| Specific Gravity, \((Gs)\) | 2.14 |
| Liquid Limit, \((LL\)% | 419 |
| Plastic Limit, \((PL\)% | 190 |
| Plasticity Index, \((PI\)% | 229 |

3. Samples preparation and testing

The mixture of Salak Tinggi residual soil with bentonite was prepared manually as shown in Table 3. The air-dried soil passing 20 mm was mixed uniformly with bentonite content at 5%, 10% and 15% by dry weight of soil. To ensure the mixed sample is evenly mixed, the sample mixture was moistened with distilled water to allow the mixture to mix thoroughly and the samples were allowed for air dried at least for 24 hours at least [10]. After that, the samples were prepared for compaction testing and the mixed soil were sealed in plastic bags and allowed to hydrate for at least 24 hour prior to compaction.

| Table 3. Detail of mixed samples. |
| --- |
| Sample | Bentonite (%) | Symbol |
| Soil | 0 | S |
| Soil + 5B | 5 | S+5B |
| Soil + 10B | 10 | S+10B |
| Soil + 15B | 15 | S+15B |

Meanwhile, the compaction test was conducted to obtain optimum moisture content \((OMC)\) and maximum dry density \((MDD)\) of mixed soil sample. Three different compaction efforts with different energies were conducted in this study as shown in Table 4 are Reduced British Standard Light \((RBSL)\), British Standard Light \((BSL)\) and British Standard Heavy \((BSH)\) [11]. The BSH and BSL compactions are based on the British Standard of the Modified and Standard Proctor compactions BS1377: Part 4:1990:3.3 and BS1377: Part 4:1990:3.5 respectively. Each compaction effort with different condition method was produced the different of compaction energy.

| Table 4. Detail of compaction characteristics [11]. |
| --- | --- | --- | --- | --- |
| Compaction effort | Weight of hammer (kg) | Height of drop (m) | No. of blows | No. of layer | Energy \((kNm/m^3)\) |
| Reduced British Standard Level \((RBSL)\) | 2.5 | 0.3048 | 15 | 3 | 336.6 |
| British Standard Level \((BSL)\) | 2.5 | 0.3048 | 27 | 3 | 605.9 |
| British Standard Heavy \((BSH)\) | 4.5 | 0.457 | 27 | 5 | 2723.5 |
The mixed samples for permeability test were prepared and mixed thoroughly with distilled water at OMC value from compaction results as shown in Figure 1. According to BS 1377: Part 6: 1990, the specimens diameter and high for permeability testing is 100 mm. However, modified specimens with dimensions from 38 mm diameter upwards may be used. Therefore, the sample size used in this study 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 taken into account from previous researchers [9-11].

After that, mixed samples were compacted accordingly to the compaction effort as shown in Table 4.

4. Results and discussion

Figure 1 show graphically the results for the compaction curve following consequences of the addition of bentonite at different compaction effort from lower energy, medium and to higher energy for RBSL, BSL and BSH respectively. The different percentage of bentonite used was affecting the value of maximum dry density (MDD) and optimum moisture content (OMC). The obvious differences in the properties of these mixed samples have significant effects on OMC and MDD values for all four types of compaction effort as shown in Figure 1.

Figure 2 present the effect of bentonite content to the MDD and OMC value at different compaction effort. It clearly seen an increase in bentonite content was decreases the MDD value for all types of compaction efforts. Conversely the OMC value is differ as the percentage of bentonite content increase, the OMC value increase. This decrement of MDD with increasing of bentonite content due to the high swelling of bentonite characteristics that forms a gel around the soil particles and causes increment in particles effective size. These was increased the void volume and decreased the dry unit weight of soil [12]. Meanwhile the increase of OMC was related to require more moisture for hydration reaction comes from the increment of fine grains size [12-13]. However, it concluded that an increase in compaction effort was increased the MDD and alter the decreases the OMC at all entire of mixed samples.
Figure 2. The effects of bentonite content at different compaction energies to the (a) MDD value (b) OMC value.

Figure 3 shows the role of various compaction efforts that give different values of MDD and OMC at different bentonite content. It shows, an increase in compactive energy was increased the MDD value and decreases the OMC value. This happen due to the higher compactive effort yields a more parallel orientation of the clay particles (which gives a more dispersed structure), the particles become closer and a higher unit weight of compaction results [13].

Figure 4 shows the result of hydraulic conductivity value for Salak Tinggi residual soil mixed with different percentage of bentonite at different compaction effort. It is clearly demonstrate the hydraulic conductivity value decrease with increment of bentonite content at each compaction efforts. It was found that the addition of 10% and 15% bentonite were gave a greater reduction in hydraulic value at each compaction compared to the addition of 5% bentonite. Moreover, the additions of bentonite content caused an increase in OMC and at the same time were resulted in reorientation of clay particles and reduction in the size of interparticle pores [14]. Instead, it shows the addition of 5%
bentonite requires high energy compaction effort for BSH to achieve low hydraulic value \((k \leq 1 \times 10^{-9} \text{ m/s})\) compared by using 10% and 15% addition of bentonite only requires low energy of compaction effort for RBSL to achieve of low hydraulic value.

**Figure 4.** The effect of bentonite content to the hydraulic conductivity value, \(k\) at different compaction efforts

Meanwhile the energy from the compaction causes the reduction of pores and these changes in pore size give in lower hydraulic conductivity. This was shown in Figure 5 that hydraulic conductivity decreases with the increasing compaction energy. The highest compaction energy at 2723.5 kNm/m³ was gave the lower hydraulic conductivity at all entire compacted mixed samples. The increasing compaction energy decreases the frequency of large pores and can eliminate the large pore mode and these changes in pore size yield lower hydraulic conductivity [14]. From Figure 5, all the three different energy applied to the mixed samples with 5%, 10% and 15% bentonite contents was resulted hydraulic conductivity less than \(1 \times 10^{-9}\) m/s. 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 [15]. In addition, increasing water content resulted in orientation of clay particles and producing the 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 [15-16].

**Figure 5.** The effect of compaction energy on the hydraulic conductivity value, \(k\) at different bentonite content
5. Conclusion
From the studies, it can be concluded that the relationship between hydraulic conductivity and compaction parameters show that the mixed soil with bentonite could be compacted with various compactive efforts to attain hydraulic conductivity value less than about $k \leq 1 \times 10^{-9}$ m/s which is the satisfactory limit recommended by various waste regulatory bodies for landfill liners. The results indicate that high compaction energy required for low bentonite content, whereas for large amount bentonite content only requires low compaction energy. The results of this study illustrates that only by applying compaction energy at optimum moisture content to the mixed soil with bentonite content is possible to compact the mixed soil to a low hydraulic conductivity. Thus the low hydraulic conductivity with certain compaction energy applied to the mixed soil could make them potential mixed materials for use as compacted soil liners in landfills areas.

6. References

[1] Liu T and Hu L 2014 Organic acid transport through a partially saturated liner system beneath a landfill Geotextiles and Geomembranes 42 428 – 436
[2] Kayabali, K. 1997 Engineering Aspects of a Novel landfill liner material: bentonite-amended natural zeolite Engineering Geology 46 105–114
[3] Baharuddin M F T, 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 Conf. (Thailand)
[4] Francisca F M and Glatstein, D A 2010 Long term hydraulic conductivity of compacted soils permeated with landfill leachate Applied Clay Science 49 187–193
[5] Benson C H, Daniel D E and Boutwell G P 1999 Field performance of compacted clay liners. Journal of Geotechnical and Geoenvironmental Engineering 5 390-403.
[6] Taha M R and Kabir M H 2005 Tropical residual soil as compacted soil liners Environmental Geology 47(3) 375–381
[7] Minerals and Geoscience Department Malaysia Updated: 2012 Geological Map of Peninsular Malaysia 8th edition Geological Map in 1985
[8] BS 1377 1990 Methods of test for soils for civil engineering purposes Part 1 – 4 (London: British Standards).
[9] Norazlan Khalid, Mazidah Mukri, Mohd Fadzil Arshad, Norbaya Sidek and Faizah Kamarudin 2019 Effect on Salak Tinggi residual soil mixed Bentonite as compacted clay liner IOP Conf. Series: Materials Science and Engineering 513 012024
[10] Norazlan Khalid and Mazidah Mukri 2017 Compaction Characteristics on Salak Tinggi Residual Soil Mixed Bentonite Electronic J. of Geotechnical Engineering 22 605-612
[11] Daniel D E and Benson C H 1990 Water content density criteria for compacted soil liners J. Geotech. Eng. 116 (12) 1811-1830
[12] Amadi A A, and Eberemu A O 2013 Characterization Of geotechnical properties of lateritic soil-Bentonite mixtures relevant to their use as barrier in engineered waste landfills Nigerian Journal of Technology 32(1) 93–100
[13] Das B M 2013 Principles of Geotechnical Engineering, 7th ed. (Stamford: Cengage Learning).
[14] Acar Y, Oliveri I 1989 Pore fluid effects on the fabric and hydraulic conductivity of laboratory compacted clay Transport Res Rec 1219 15–22
[15] Osinubi K J and Nwaiwu C M O 2006 Hydraulic Conductivity of Compacted Lateritic Soil J. Geotechnical and Geoenvironmental Eng. 131 1034 – 1041.
[16] Amadi A A, Afolayan J O and Osinubi K J 2014 Sensitivity Analysis of the Hydraulic Conductivity of Compacted Lateritic Soil and Bentonite Composite Geo-Congress Technical Paper 921-930
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