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Bentonite Enhanced Soil as an Alternative Landfill Liner in Rikut Jawu, South Barito

Yulian Firmana Arifin[1*], **Sambelum**[2]

[1] Civil Engineering Study Program, University of Lambung Mangkurat, Banjarmasin
[2] Office of Public Works and Spatial Planning, Tamiyang Layang, South Barito

*Corresponding author: y.arifin@ulm.ac.id

Abstract. The use of geosynthetic materials has developed very rapidly; however, the use of clay as a mineral barrier is a necessity to meet environmental requirements to protect groundwater from leachate in landfills. Generally, the soil used as a mineral barrier is local land or close to landfill locations. It is just often found that local land does not meet the requirements as a barrier. This condition occurs in landfill development in Rikut Jawu, South Barito regency. The permeability of the surrounding land that has been compacted is still higher than the required permeability. An effort is needed so that the permeability can be accepted. This paper describes the effort to minimize the permeability of sandy loam soils in Rikut Jawu to meet the requirements as a landfill liner. This research was conducted in the Laboratory of Soil Mechanics, University of Lambung Mangkurat. Disturbed soil samples were mixed with bentonite with the percentages of 1%, 5%, 10%, 15%, 20% based on dry weight. Water was added depending on the optimum moisture content of each mixture that was obtained from the Standard Proctor compaction test. Series of the permeability tests were performed according to ASTM standard. In order to investigate the time effect, the samples were cured for periods of 3, 7, and 14 days. The result shows that the presence of bentonite in the mixture influences the permeability (k) of samples. The permeability of samples decreases from 1.3×10^{-5} cm/s to 3.6×10^{-7} cm/s. The result also found that the permeability of bentonite enhanced soil was also influenced by the water content of compaction. The curing times of 3, 7, and 14 days do not significantly affect the permeability. The percentage of bentonite to be used as a clay liner to fulfill permeability requirement is 50%. The further efforts are suggested and discussed in the paper.

1. Introduction
Although the use of geosynthetic materials in the construction of landfills has increased rapidly, the clay liner as a barrier material is still being used. Some Europe countries such as Germany, Austria, France, Belgium, and Italy, USA and Asia such as Japan require the use of mineral barriers as part of different landfill liner systems with varying thickness and permeability [1, 2].

The need for a liner system that meets the current requirements is tremendous. Before the presence of commercial materials such as geomembrane, geosynthetic clay liner (GCL) and bentonite-sand-polymer mixture materials such as Trisoplast, the liner used was local material at the nearest landfill or quarry location. The use of the local material is not a problem as long as it is suitable, available in sufficient quantities, and fulfilling the requirements [3, 4, 5, 6]. The use of local materials also benefits from costs [3, 4].

This happens in the development of the Rikut Jawu landfill, South Barito regency. Land available in large quantities in the field is a type of silty clay with a permeability of 1.3x10^{-5} cm/ s. This is greater than the requirements of 1.0x10^{-7} cm/s [1, 2]. For natural conditions, SNI 03-3241-1994 requires that the land around the landfill must have permeability smaller than 1.0x10^{-6} cm/s [7]. Therefore, an effort is needed to reduce the value of permeability.

Several efforts can be made to minimize the value of soil permeability as a mineral barrier. An example attempt was by mixing the soil with bentonite [8]. This effort succeeded in reducing the permeability of the soil used with a maximum percentage of 20%. Moreover, the value of permeability tends to be constant. The permeability of the compacted soil is also influenced by compaction energy and water content [9]. The soil compacted using modified Proctor compaction effort has lower permeability than that of compacted using standard Proctor. At water content higher than optimum moisture content (or wet of optimum) the permeability is lower than dry of optimum.

The soil liners may not entirely impermeable to fluid movement. However, the use of proper materials will reduce contamination of groundwater from leachate as an important issue related to the environment. This paper discusses the use of local materials to be used as mineral barriers at TPA Rikut Jawu, South Barito regency. The efforts made with the addition of bentonite to improve the permeability of the material used are also discussed in this paper.

2. Material and Methods

2.1. Material Used

The materials used in this study were mixtures of local soil from Rikut Jawu and commercial bentonite sold in Indonesia. Physical and engineering properties of soil and bentonite are summarized in Table 1. As shown in the table, the materials have significantly differences in engineering properties (*i.e.*, Atterberg limits, shear strength, fine content, and the permeability). The high liquid limit, plasticity index, and fine content of the bentonite are required to reduce significantly the permeability of the local soil used.

Table 1. Physical and engineering properties of soil and bentonite used.

Soil Parameter	Local soil	Bentonite [10]
Specific Gravity	2.59	2.78
Liquid limit (%)	34.00	140
Plastic limit (%)	20.73	55
Plasticity index (%)	13.27	85
Cohesion (kPa)	15	30
Internal friction angle (°)	4.35°	20°
Fine content (%)	52.58	100
Dry density (Standard Proctor compaction test) (Mg/cm^3)	1.50	1.20
Optimum moisture content/OMC (%)	7.00	40
Permeability at maximum dry density condition (cm/s)	1.3×10^{-5}	1.9×10^{-8}

2.2. Methods

The local soil sample was mixed with 1, 5, 10, 15, and 20% of bentonite on a dry mass basis (*i.e.*, the ratio between the dry weight of bentonite and dry weight of soil sample (w/w) that was back calculated from the respective water content of the materials). The Proctor compaction tests (ASTM D698) were performed for each mixture to obtain the maximum dry density and optimum moisture content (OMC). Permeability tests according to ASTM D 5856-95 were conducted to get the coefficient of permeability (k) for samples compacted at OMC and wet of optimum (*i.e.*, 4% higher than OMC). In order to investigate the time effect on k, the samples were cured at time periods of 3, 7, and 14 days before testing.

3. Results and Discussions

Figures 1(a) and 1(b) show the effect of bentonite content on the OMC and maximum dry density of compacted soil and bentonite mixtures, respectively. As shown in Figure 1(a), the OMC increases from 7% for the local soil to 25% for mixture with bentonite content of 20%. By combining with the data reported by [10], the OMC curve increases to 40% (*i.e.*, at 100% bentonite). It can be concluded that the increase in bentonite content results in increasing optimum water content as shown in Figure 1(a). However, the maximum dry density decreases significantly from 1.5 Mg/m^3 to local soil to 1.28 Mg/m^3 at a bentonite content of 20%. The dry density decreases slightly to 1.2 at 100% bentonite (data reported by [10]). It seems that the bentonite plays a significant role at the percentage higher than 20% where the water content increases and the dry density approaches the density of bentonite.

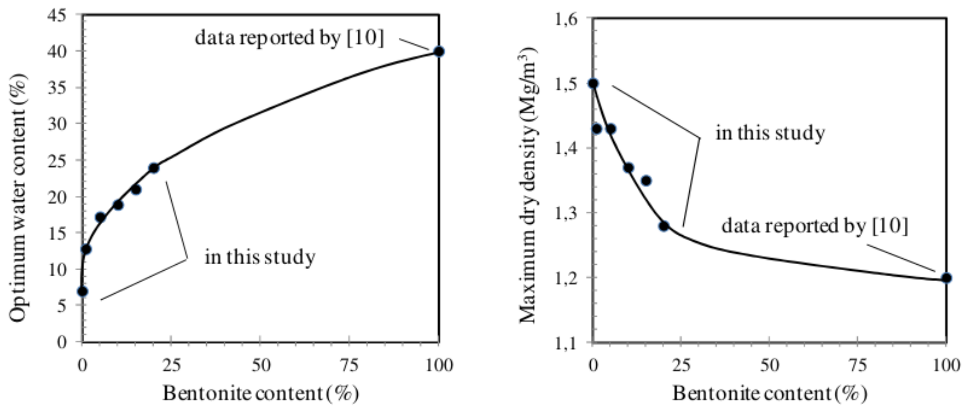

Figure 1. Bentonite content effects on (a) optimum water content and (b) maximum dry density

Figure 2 shows permeability of compacted soil-bentonite mixtures as a function of bentonite content for two water content conditions (*i.e.*, at optimum moisture content and 4% higher than optimum water content). As shown in Figure 2, the permeability of the mixtures decreases significantly from $5.4x10^{-5}$ to $8.47x10^{-7}$ cm/s by the addition of bentonite to 5%. The reduction continues slightly to $3.4x10^{-7}$ cm/s at the maximum percentage of bentonite used in this study (*i.e.*, 20%).

At higher water content (*i.e.*, 4% higher than optimum moisture content), the permeability as a function of bentonite content curve is placed over the other curves. It means that its permeability is higher than that of the sample at OMC. At 4% higher than the OMC, the dry density decreases from 90-94% $\gamma_{d\ max}$ (Table 2). In this condition, permeability is more controlled by dry density than water content.

Figure 3 shows permeability of soil-bentonite mixture at OMC with different curing time (*i.e.*, 3, 7, and 14 days). As shown in the figure, the permeability curves placed very close to each other exhibits less significant effect of curing time on the permeability of the mixtures. The behaviors of compacted bentonite are time-dependent due to its microstructure that consists of macro and micro-pores [11, 12]. For unsaturated condition, it seems that hydraulic equilibrium between the pores of different levels is not reached in a short time. Since the test performed in this study was the saturated permeability test, time does not play a significant role in the permeability result.

Several attempts have been made so that the mixtures can be used as a mineral barrier in Landfill. However, the permeability obtained does not meet the requirements of less than $1x10^{-7}$cm/s. Figure 4 shows the permeability curve as a function of bentonite content by combining data acquired in this study with data reported by [10]. As shown in the figure, the percentage of bentonite required to satisfy is 50%. It seems that at the percentage of bentonite less than 20%, the void is not entirely filled by bentonite. According to [13], the void of mixtures is filled by bentonite at a percentage of 20% or more. This method can be used, but many considerations must be taken into accounts such as difficult compaction processes and expensive costs.

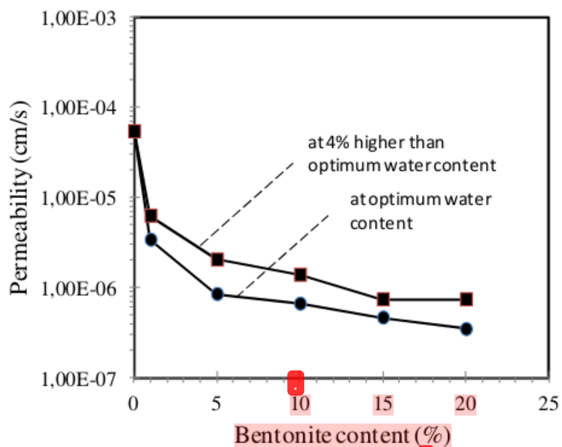

Figure 2. The permeability of samples as a function of bentonite content: compaction water content effect

Another effort that can be considered in order to reduce the permeability of clay liner is by increasing the compaction effort from standard Proctor to modified Proctor compaction. The increase in compaction effort reduces the macropores of compacted bentonite [12]. These pores play a significant role in the saturated permeability of compacted bentonite [13]. Further investigation must be taken to obtain definite results of the permeability by increasing compaction energy.

Table 2. Dry density of the mixtures at wet of optimum (4% higher than OMC)

Bentonite (%)	$\gamma_{d\ max}$ (Mg/m^3)	$\gamma_{d\ at\ +4\%OMC}$ (Mg/m^3)	% $\gamma_{d\ max}$
1	1.43	1.35	94
5	1.43	1.33	93
10	1.37	1.24	91
15	1.35	1.21	90
20	1.28	1.19	93

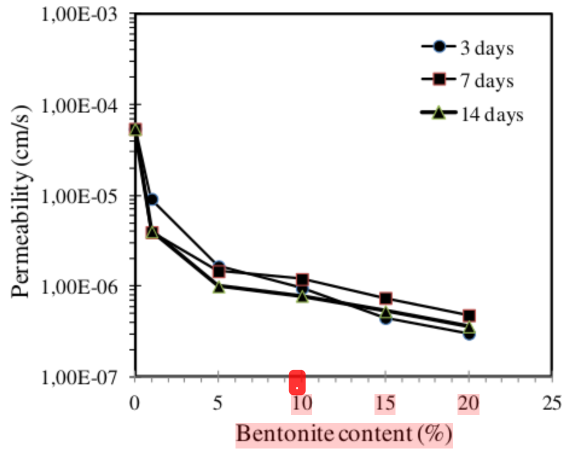

Figure 3. The permeability of samples as a function of bentonite content: curing time effect

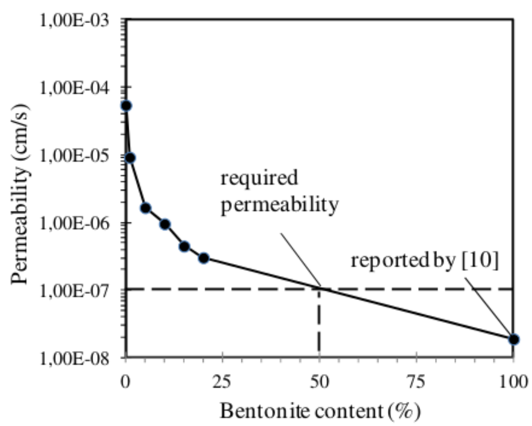

Figure 4. Bentonite content and required permeability

4. Conclusions

The results of the study on the use of soil-bentonite mixtures as an alternative barrier have been presented. The result reveals that the bentonite plays a significant role at the percentage higher than 20% where the optimum water content increases and the dry density approaches the density of pure bentonite. The permeability of the mixtures decreases significantly by increasing bentonite content from 1-5%. The sample that compacted at wet of optimum (*i.e.*, 4% higher than OMC) has higher permeability than that of compacted at OMC. Curing time as an attempt to reach required permeability does not influence significantly on the permeability of the mixtures. It takes approximately 50% bentonite content to satisfy the permeability requirements of mineral barriers (*i.e.*, 1×10^{-7} cm/s).

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