DEVELOPMENT OF A LANDFILL CLAY LINER USING LOCALLY AVAILABLE EXPANSIVE SOIL

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Abstract

Solid waste is a growing problem in urban areas of Sri Lanka and management of waste, both liquid and solid has become a critical environmental concern due to absence of engineered methods of disposing waste. Development of a simple engineered landfill facility utilizing locally available materials to suit landfill liner requirements is the most economical and the timely solution to this problem. In the present study, it was investigated the suitability of expansive soil which is commonly available in the south arid zone of Sri Lanka to use as clay liners in landfill facilities. The engineering properties of soil were improved by the addition of commercially available bentonite to build a low hydraulic conductivity barrier. Further, the long term effect of soil-leachate interaction on hydraulic conductivity of the suggested liner was studied. Results showed that the engineering properties of expansive soil can be improved by the addition of bentonite to meet the landfill liner requirements. However, the original engineering properties of soil-bentonite mixtures were significantly affected by the leachate interaction over a long period of time.

Keywords: Clay liner, expansive soil, bentonite, hydraulic conductivity, soil-leachate interaction

1. Introduction

Solid waste, especially Municipal Solid Waste (MSW), is a growing problem in urban areas of Sri Lanka and management of waste, both liquid and solid has become a critical environmental concern. The absence of engineered methods of disposing waste and the open dump approach adapted has created this major environmental and social problem of waste within most of the cities. Under open dumping, which is the main trend among local authorities at present, solid waste are disposed haphazardly and they are subsequently subjected to open burning.

Currently, the attention given to the solid waste management in dry zone especially in arid zone of the country is very low due to the fact that all most all the major cities in Sri Lanka are situated in wet zone. However, solid waste management in dry zone is very important as people in this area depend very much on ground water for their drinking purposes and therefore, the contamination of ground water especially by the leachate generated in waste disposal sites should be kept at a minimum by following engineered waste disposal methodologies.

Engineered landfilling is one of the best options to overcome the problems associated with contamination of ground water with leachate [Bagchi, 2004; David, 1993]. The liner system in an engineered landfill acts as a barrier for leachate and prevents the transportation of contaminants to the surrounding pollution prone environment. Hence liner system in a landfill becomes one of the critical design considerations [Bagchi, 2004; David, 1993]. A landfill liner is intended to be a low permeable barrier which is generally involves with the application of clay or synthetic material layer [Bagchi, 2004; David, 1993; Jayasekera, 2007]. Since, synthetic materials are very expensive, Compacted Clay Liners (CCL) is the most suitable liner system for developing countries [Ameta et al., 2007].

Expansive soil is a very commonly available material in the south arid zone of the country and which can be used as a liner material. Expansive soil mainly consists of fine grained clay which occurs naturally and is subject to swelling and shrinkage, varying in proportion to the amount of moisture present in the soil [Gourley et al., 1993].

Only a limited number of researches are reported with respect to utilization of expansive soil as a CCL material in landfill sites [Jayasekera, 2007]. Therefore, a compacted clay liner was developed using locally available expansive soil in this research study. Further, long term effect of soil-leachate interaction on engineering properties of suggested clay liner was investigated.

2. Methodology

2.1 Engineering properties of Expansive soil

In order to investigate the suitability of expansive soil to use as a clay liner, basic engineering properties of original soil collected from Hambantota were determined in the laboratory and presented in Table 1. The column corresponding to 0 % bentonite represents the basic engineering properties of unimproved expansive soil. It can be seen that expansive soil is a highly plastic material.

X-ray diffraction test is the most accurate methodology to determine the mineral content of the soil. However, due to limited facilities available and high cost involved, the mineral content could not be found through x–ray diffraction method in this research study. Based on an empirical chart proposed by Savage, 2007, using Atterberg limits and clay content, it was realized that Illite is the most dominating clay mineral in this particular expansive soil.

Table 1: Engineering properties of soil-bentonite mixtures

Physical Property	*Bentonite Percentage*			
	0 %	*5 %*	*10 %*	*15 %*
Fine Content (%)	*67*	*70*	*76*	*79*
Clay Content (%)	*55*	*62*	*65*	*68*
Sand Content (%)	*33*	*30*	*24*	*21*
Liquid Limit (LL) (%)	*41*	*41*	*43*	*49*
Plastic Limit (PL) (%)	*24*	*28*	*30*	*22*
Plasticity Index (PI) (%)	*17*	*13*	*13*	*27*

Linear Shrinkage (LS) (%)	*16*	*17*	*19*	*31*
Max. Dry Unit Weight (kN/m^3)	*17.0*	*16.9*	*16.6*	*16.3*
Optimum Moisture Content (%)	*19.0*	*19.5*	*22.0*	*28.0*

Swelling potential of expansive soil was determined in accordance with Australian Standard AS 1289.7.1.1(2003) in this research study. The swelling potential is defined in terms of Shrink–Swell Index. By laboratory experiments it was realized that Shrink-Swell Index of the soil is 1.48 %, which can be considered as medium swelling potential material.

In addition to the physical properties, hydraulic characteristics of the original material compacted at optimum moisture content, representing the compacted clay liners, were determined in the laboratory using falling head permeability test.

2.2 Improvement of engineering properties of Expansive soil

In order to improve the engineering properties of natural expansive soil, different percentages of bentonite varying from 0 to15 % in steps of 5 % on dry weight were mixed with expansive soil and improved properties are depicted in Table 1. The bentonite is an important naturally occurring clay mineral of great commercial importance possessing inherent bleaching properties [Stewart et al., 2003]. It falls mainly under montmorillonite mineral group and presents strong colloidal properties.

Further variations of hydraulic characteristics of soil-bentonite mixtures were studied.

2.3 Long term effect of soil-leachate interaction

The long term effect of soil-leachate interaction on hydraulic conductivity and volume change properties of liner material was evaluated by allowing the compacted soil-bentonite mixtures to interact with leachate for a period of four months. After soil-bentonite mixture interact with leachate for a sufficient time, change of hydraulic conductivity was evaluated in the laboratory using falling head permeability test.

3. Results and Discussion

3.1 Particle size distribution

Particle size distribution plays a crucial role in evaluating the suitability of a soil to use as the liner material in a landfill site. The fine fraction should be high with low gravel content to ensure a low hydraulic conductivity through the soil.

The particle size distribution of soil-bentonite mixtures are presented in Figure 1. It can be seen that fine fraction of the natural expansive soil is about 67 % and clay content is about 55 %. This means that natural soil itself contains a higher fraction of fines. The desired value of fine content of a landfill liner material is equal or greater than 20-30%. Therefore, the natural soil also satisfies this requirement. Since fine fraction of the bentonite is 100 %, with the addition of bentonite to natural soil, fine content and clay fraction have been increased significantly as shown in Table 1. Conversely, it can be noted that percentage of sand content decreases with the increase of percentage of bentonite.

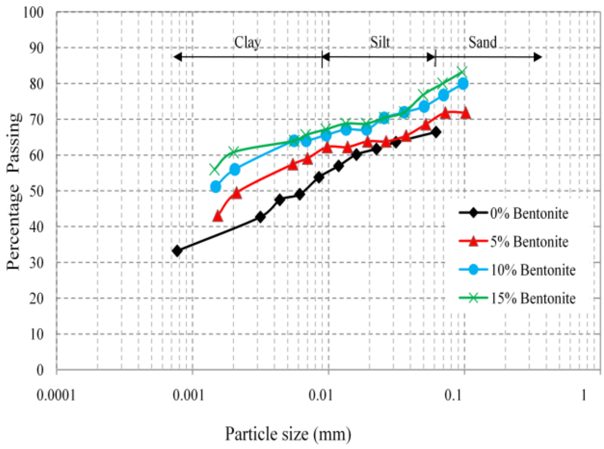

Figure 1 – Particle size distribution of soil-bentonite mixtures

3.2 Plasticity Index

Variation of Atterberg limits with the addition of bentonite is presented in Figure 2. It can be seen that liquid limit of soil-bentonite mixtures gradually increases with the increase of bentonite content. A significant increase in liquid limit can be observed when the bentonite percentage is more than 10 %.

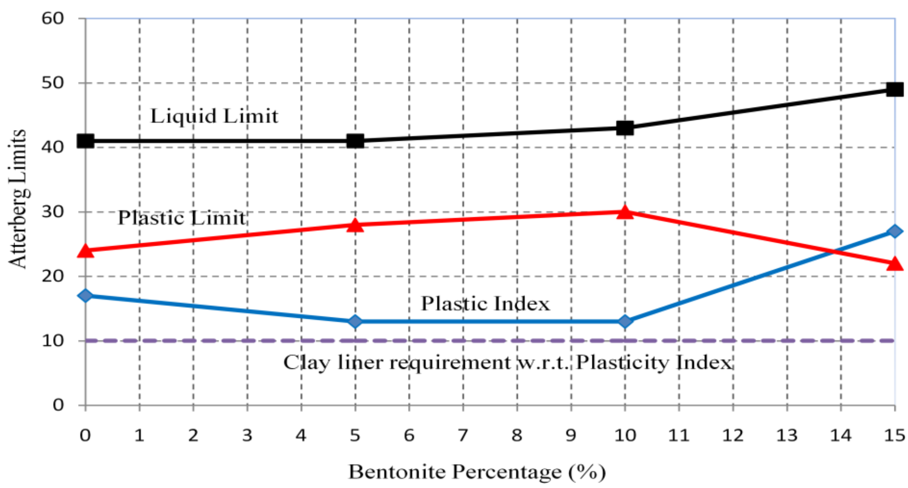

Figure 2 – Variation of Atterberg Limits with bentonite percentage

Plasticity index is an another parameter which should be checked against the landfill liner requirements. It can be observed that liquid limit increases with the addition of bentonite whereas the plastic limit has no such relationship. Plastic limit increases with the addition of bentonite up to 10% and it has been reduced with further addition of bentonite. It can be seen that, the rate of increase of plastic limit is more than that of liquid limit up to the 10% bentonite addition, hence plasticity index decreases.

Plasticity index doesn't show any clear relationship with respect to the percentage of bentonite added. Initially plasticity index decreases up to the 10 % of bentonite content, and further addition of bentonite shows a huge increase in plasticity index. However, the requirement of a landfill liner material which is plasticity index should be more than 7-10% is satisfied in all soil-bentonite mixtures [David, 1993].

Further, Table 1 shows that linear shrinkage limit of soil-bentonite mixtures were gradually increases over bentonite content. The significant increase of plasticity index and linear shrinkage limit over 15% bentonite is due to the high water absorption capacity of bentonite.

3.3 Compaction Characteristics

The variation of compaction characteristics of soil-bentonite mixtures are presented in Table 1 and Figure 3. It can be seen that maximum dry unit weight decreases whereas the optimum moisture content increases with the addition of bentonite. The decrease in maximum dry unit weight with increase in bentonite content may be attributed to high swelling characteristics of bentonite that forms a gel called as diffused double layer around soil particles. When this diffused double layer forms around the soil particles, the effective size of soil particles increases which causes increase in void volumes and thus decreased dry unit weights. The optimum moisture content increases over the bentonite content is due to the high water absorption capacity of bentonite.

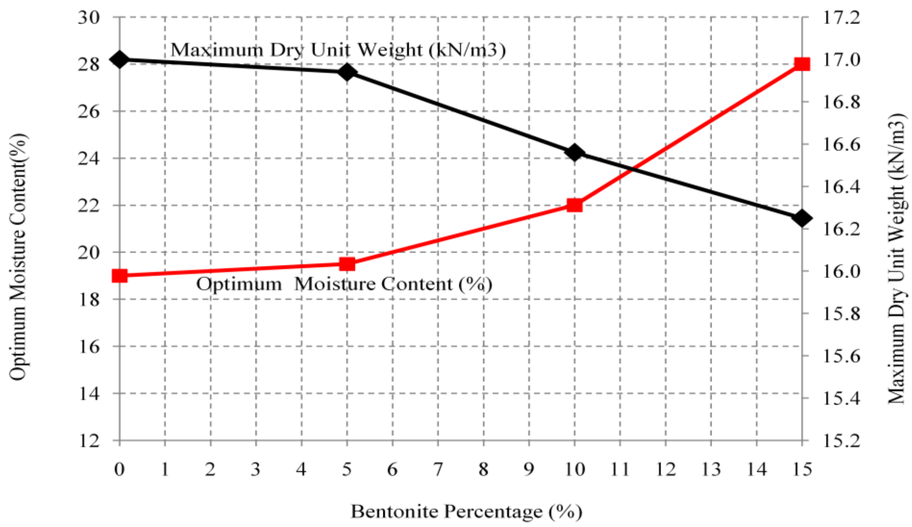

Figure 3 – Variation of compaction characteristics over bentonite content

3.4 Hydraulic Conductivity

The variation of hydraulic conductivity of soil-bentonite mixtures is illustrated in Figure 4. It can be noted that the hydraulic conductivity of soil-bentonite mixtures decrease with the increase of bentonite. With the increase of bentonite, which mainly consists of montmorillonite mineral, the diffused double layers surrounding the clay particles are getting thicker (Figure 5). As a result, the flow paths between the double layers become pinched off and the hydraulic conductivity decreases. Further, according to the Gouy-Chapman theory, the hydraulic conductivity is inversely proportional to the double layer thickness. Another notable feature is that, hydraulic conductivity is significant reduced with the addition of bentonite to the original soil. The clay liner requirement with respect to hydraulic conductivity, i.e. 1×10^{-9} m/s, can be achieved with the addition of 10% of bentonite to the original soil.

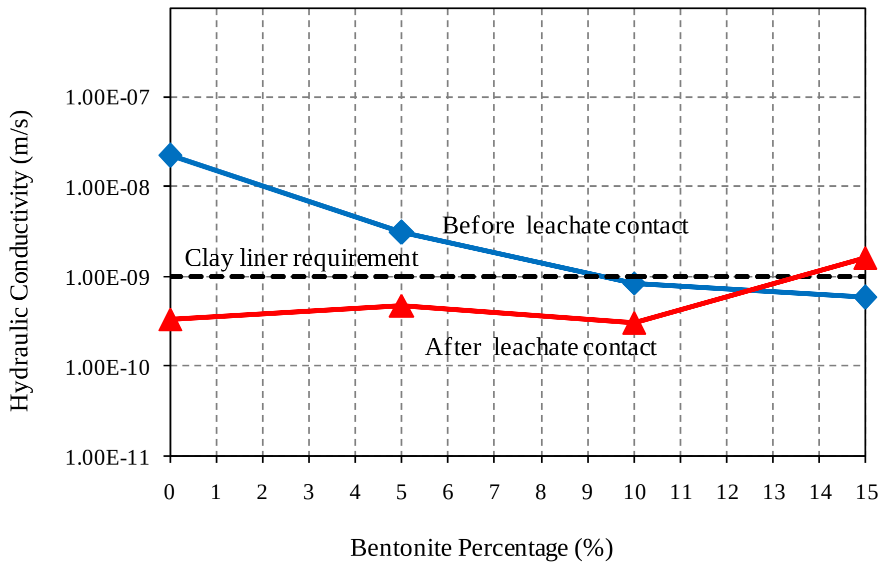

Figure 4 – Variation of hydraulic conductivity with bentonite percentage

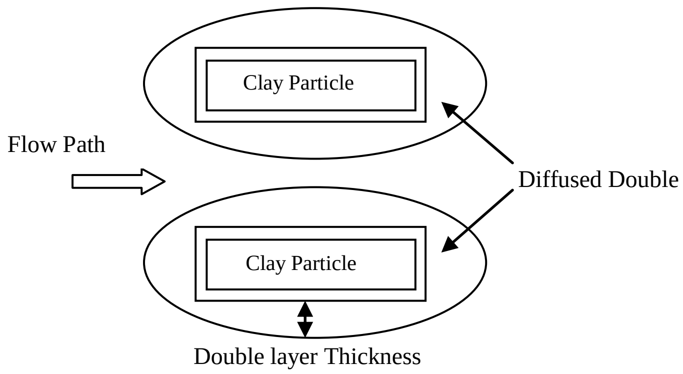

Figure 5 – Reduction of hydraulic conductivity due to increase of double layer

On the other hand, due to the formation of diffused double layer creates repulsive forces along the sides of the clay particles making it difficult for individual clay particles stay closer to each other. Under these repulsive forces, these clay particles align themselves in a more parallel orientation forming a dispersed structure; hence increase the void ration over the increase of bentonite percentage. (Figure 6)

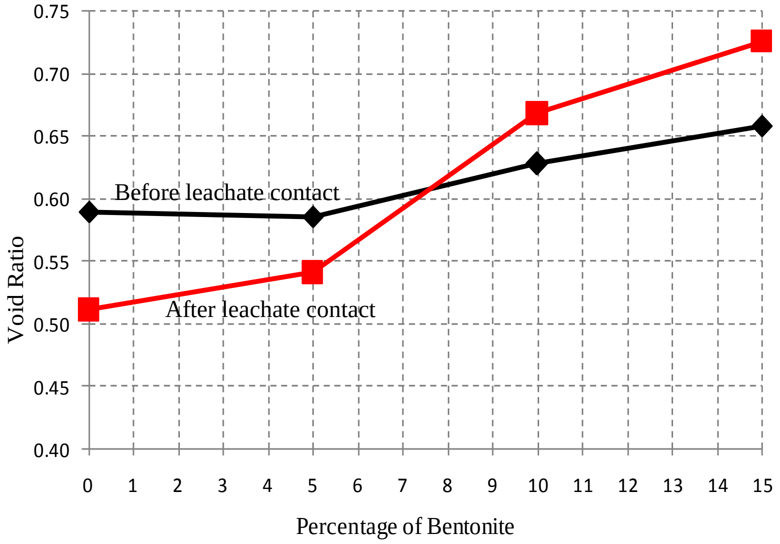

Figure 6 – Variation of void ratio with the addition of bentonite

According to the above results hydraulic conductivity is the governing factor to select the best percentage of bentonite that should be mixed with expansive soil as all the other clay liner requirements are satisfied with the natural soil itself. Therefore, mixing 10% of bentonite by weight with expansive soil yields the best mixture for a clay liner and the comparison of clay liner requirements with those mixture properties are given in Table 2.

Table 2 – Clay liner requirements

Engineering Property	*Clay liner requirement*	*Expansive soil + 10% bentonite*
Hydraulic conductivity	$\leq 1\times10^{-9}\ ms^{-1}$	$8.56\times 10^{-10}\ ms^{-1}$
Plasticity index	$\geq$ *7-10 %*	*13 %*
Percentage fines	$\geq$ *20-30 %*	*75 %*
Percentage gravel	$\leq$ *30%*	*< 2 %*
Maximum particle size	$\leq$ *25-50 mm*	*2 mm*

3.5 Engineering properties of Soil-Bentonite mixtures after a long term leachate contact

Long term effect of soil-leachate interaction on hydraulic conductivity is the major factor which determines the satisfactory performance of a landfill liner. The variation of hydraulic conductivity of compacted soil-bentonite mixtures after contact with leachate is also illustrated in Figure 4. It can be seen that hydraulic conductivity of original compacted expansive soil has been decreased significantly after the interaction with the leachate. However, with the increase of bentonite percentage the hydraulic conductivity has been slightly increased and when it comes to a bentonite percentage of about 14%, hydraulic conductivity has been increased comparing to the before leachate contact state. Consequently, clay liner requirement gets dissatisfied.

This reduction of hydraulic conductivity in original expansive soil after contact with the leachate is mainly associated with the clogging of soil particle tops due to precipitation of the suspended particles existing in the leachate and form a less permeable thin layer at the top. The slight increase of hydraulic conductivity over the soil-bentonite mixture after contact with the lachate is mainly due to reduction of diffuse double layer thickness, which causes increase of flow paths between the diffused double layers. In other words, soil-bentonite mixture has become less reactive (decrease swelling potential) after contact with leachate for a certain period. This is mainly due to the physic-chemical reactions between leachate and soil-bentonite mixture.

Similar results can be observed with respect to void ratio as shown in Figure 6 in soil-bentonite mixture after contact with leachate. The void ratio has been increased with the addition of bentonite, due to the effect of diffused double layer, where repulsive forces of clay particles increased the void spaces. The reduction of void ratio in the original expansive soil after interact with the leachate is mainly due to the precipitation of the suspended particles existing in the leachate, in the void spaces of soil, which leads to increase the volume of solid state in the soil; thus void ratio has been reduced.

4. Conclusions

Engineering properties of expansive soil can be well improved by mixing it with different percentages of bentonite. However, the rate of improvement of those properties gets reduced with the increasing bentonite percentage. Therefore, excessive addition of bentonite to expansive soil will not form a suitable mixture to suit clay liner requirements.

All the clay liner requirements other than the hydraulic conductivity get satisfied by the natural expansive soil itself and therefore hydraulic conductivity is the governing factor which determines the most efficient percentage of bentonite. According to the laboratory experiments it can be concluded that addition of 10% of bentonite by weight will yields the most economical soil-bentonite mixture to build clay liners.

The original engineering properties of soil-bentonite mixtures can be significantly affected by leachate interaction over a period of time. After interact with leachate, the hydraulic conductivity has been significantly decreased in the original expansive soil whereas it has been slightly increased with the increase of bentonite percentage. Therefore, it can be concluded that, the satisfactory performance of the compacted clay liner is highly depends on the alteration of soil structure due to the soil-leachate interaction over a long period. These consequences will affect the satisfactory performance of the clay liner over time.

5. Acknowledgement

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