Suitability of Expansive Soil to Use as Clay Liners in Arid Zone of Sri Lanka

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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 have become a critical environmental concern due to the absence of engineered methods of disposing waste. Development of a simple engineered landfill facility utilizing a locally available material 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 soil was 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 period of time.*

Keywords: *expansive soil, hydraulic conductivity, landfill liner, leachate.*

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 have 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 the people 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.

Bagchi (2004) and Daniel (1993) had identified that engineered land filling is one of the best options to overcome the problems associated with contamination of ground water with leachate. 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), Daniel (1993) and Jayasekera (2007) had studied the hydraulic conductivity of different landfill liners and according to the results a landfill liner is intended to be a low permeable barrier which is generally involves the application of clay or synthetic material layer. Since, synthetic materials are very expensive, compacted clay liners (CCL) are the most common liner system in developing countries. (Ameta et al, 2008)

Expansive soil is a locally available material in Hambantota area which can be used as a liner material. Gourley et al (1993) had investigated the engineering properties of expansive soil and had defined expansive soil as fine grained clay which occurs naturally and subjects to swelling and shrinkage, varying in proportion to the amount of moisture present in the soil.

Only a limited number of researches are reported with respect to investigation of suitability of expansive soil to use as a CCL material in landfill sites. Therefore, a compacted clay liner was developed using expansive soil in this research study. Further, 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.

Table 1 Engineering properties of soil-bentonite mixtures

Physical Property	Bentonite Percentage			
	0%	5%	10%	15%
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
Maximum Dry Unit Weight (kN/m^3)	17.00	16.94	16.56	16.25
Optimum Moisture Content (%)	19.0	19.5	22.0	28.0

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

Swelling potential of expansive soil can be determined in accordance with both British Standards and Australian Standards. According to the British Standard, swelling potential is defined in terms of swelling pressure whereas according to the Australian Standards, swelling potential is defined in terms of Shrink – Swell Index. In this research study shrink-swell index was evaluated according to the AS 1289.7.1.1(2003) in order to present the swelling potential of the expansive soil and shrink-swell index was recorded as 1.48%.

According to AS 1289.7.1 (2003) Shrink-swell index can be found by shrink swell test which consists of two separate laboratory tests, a swell test and a simplified core shrinkage test. These tests should be carried out on undisturbed soil samples from their initial field moisture contents.

As fine content of the soil is high, falling head method was used to determine the hydraulic conductivity of expansive soil. The major difficulty encountered during the experiment was saturation of the soil sample. As soil sample was compacted at its optimum moisture content to represent the clay liner in an engineered landfill site, it takes very long time for the saturation process. In order to overcome this difficulty, a vacuum was applied from top of the sample while sample was submerged in water.

2.2. Improvement of Engineering Properties of Expansive Soil

Different percentages of bentonite varying from 0-15% in steps of 5% on dry weight were mixed with expansive soil in order to improve the engineering properties of soil and depicted in Table 1.
Stewart et al (2003) had defined bentonite as an important naturally occurring clay mineral of great commercial importance possessing inherent bleaching properties. It falls mainly under montmorillonite 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 leachate contact 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.

3. RESULTS AND DISCUSSION

3.1. Engineering Properties of Soil-Bentonite Mixtures

Variation of engineering properties with the addition of bentonite is presented in Table 1. According to the laboratory test results with the addition of bentonite, Atterberg limits tend to increase. Similarly maximum dry unit weight decreases whereas the optimum moisture content increases. The large increase in liquid limit, linear shrinkage and optimum moisture content when the bentonite percentage is 15% may be due to the high water absorption of bentonite.

3.1.1. Compaction Characteristics

The variation of maximum dry density and the optimum moisture content with the addition of bentonite is clearly illustrated in Figure 1.

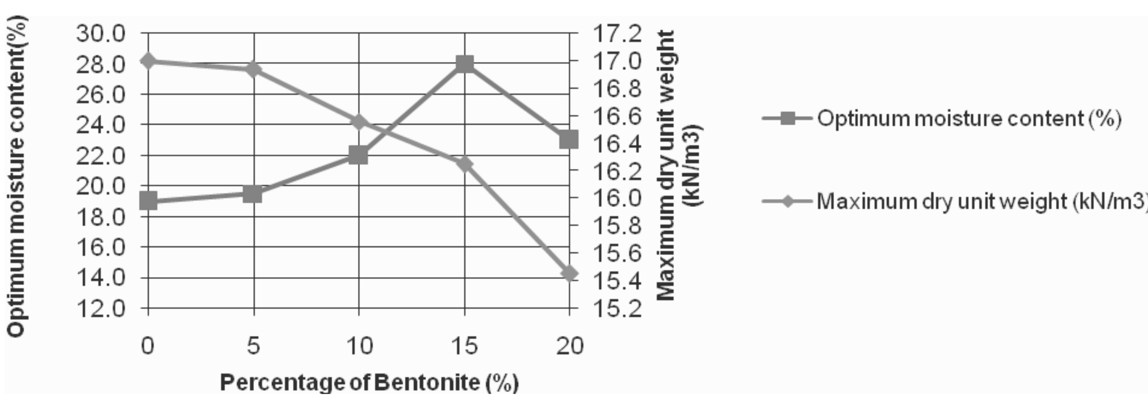

Figure 1 Variation of maximum dry unit weight and optimum moisture content with bentonite percentage

It can be observed that as the bentonite percentage increases, the maximum dry unit weight decreases whereas the optimum moisture content increases except the case of 20% bentonite addition. 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.

3.1.2. Hydraulic Conductivity

The variation of hydraulic conductivity of soil-bentonite mixtures is illustrated in Figure 2. It can be noted that the hydraulic conductivity of soil-bentonite mixtures decrease with the increase of bentonite.

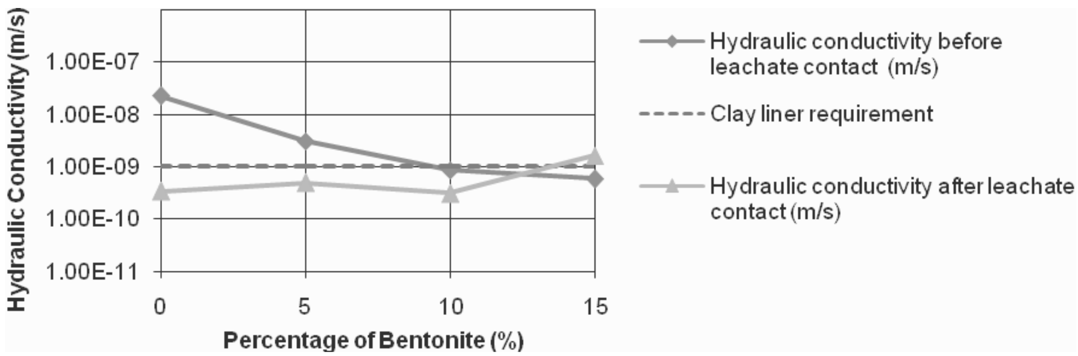

Figure 2 Variation of hydraulic conductivity with bentonite percentage

With the increase of bentonite, which mainly consists of montmorillonite mineral, the diffused double layers surrounding the clay particles are getting thicker. (Figure 3) 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. It can be noted that, a significant reduction in hydraulic conductivity 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. [Bagchi (2004), Daniel (1993) and Iqbal et al (2003).

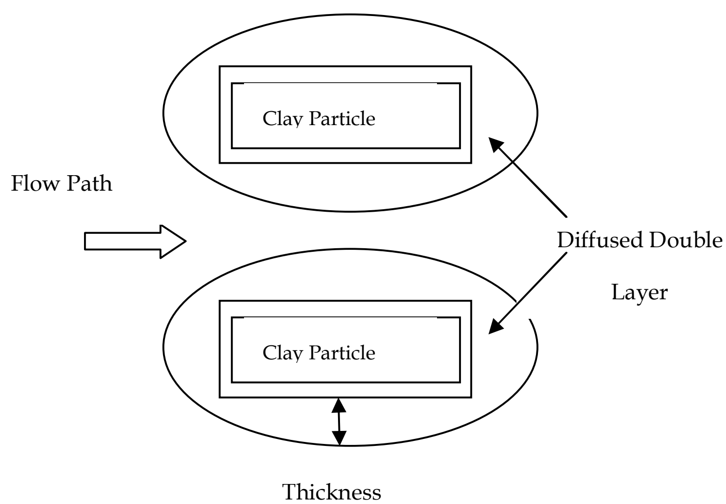

Figure 3 Reduction of hydraulic conductivity due to increase of double layer thickness

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 4)

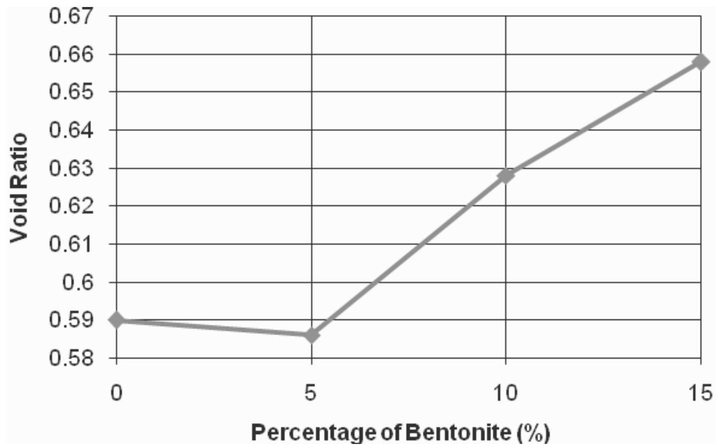

Figure 4 Variation of void ratio with the addition of bentonite

3.1.3. Plasticity Index

Plasticity index is another parameter which should be checked against the landfill liner requirements. Results of the laboratory Atterberg tests are presented graphically in Figure 5.

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% of bentonite. However, the rate of increase in both the liquid limit and plastic limit are almost similar.

Plasticity index doesn't show any clear relationship with respect to the percentage of bentonite added. Initially plasticity index decreases and with the addition of 15% of bentonite it shows a huge increase. But for 5% and 10% plasticity index is almost similar and this may be due to the same rate of increase in liquid and plastic limits. However, the requirement of a landfill liner material which is plasticity index should be more than 7-10% is satisfied for all soil samples. [Bagchi (2004), Daniel (1993) and Iqbal et al (2003).

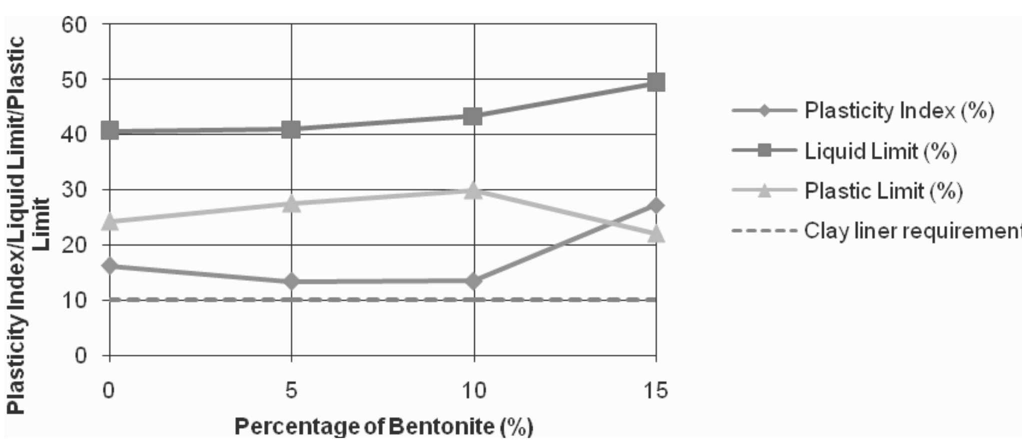

Figure 5 Variation of Liquid Limit, Plastic Limit and Plasticity Index with bentonite percentage

3.1.4. 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. According to the results of the sieve analysis and hydrometer analysis the fine content of the natural expansive soil is 66%. 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%. [Bagchi (2004), Daniel (1993) and Iqbal et al (2003)] Therefore, the natural soil also satisfies this requirement. Since bentonite contains a higher fraction of clay minerals this fraction of fines in natural soil is expected to be increased with the addition of bentonite. Results of hydrometer analysis for different percentages of bentonite addition are shown in Figure 6.

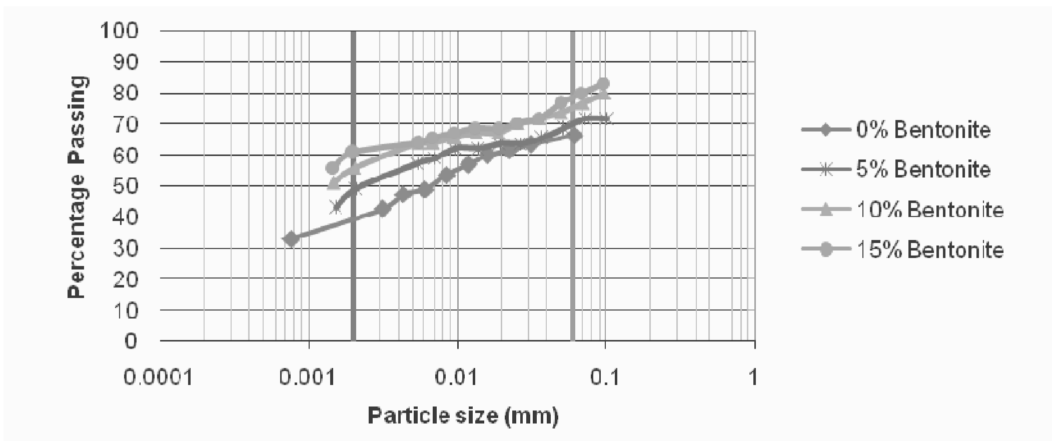

Figure 6 Particle size distribution curves of different soil-bentonite mixtures

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, as suggested in section 3.1.2 mixing of 10% of bentonite by weight with expansive soil yields the best mixture for a clay liner and the comparison of clay liner requirements with that 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}	8.56×10^{-10} ms^{-1}
Plasticity index	≥ 7-10 %	13 %
Percentage fines	≥ 20-30 %	75 %
Percentage gravel	≤ 30%	< 2 %
Maximum particle size	≤ 25-50 mm	2 mm

3.2. Engineering Properties of Soil-Bentonite Mixtures after 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 2. 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 3 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. There is no any significant effect on the other clay liner requirements from the long term leachate interaction. Therefore, hydraulic conductivity becomes the governing factor which determines the optimum percentage of bentonite.

According to these results compacted natural expansive soil will also act as a hydraulic barrier after the attenuation by landfill leachate for a certain period of time. On the other hand there is an optimum percentage of bentonite that should be added to expansive soil to build a clay liner in landfill facilities since the soil structure will be altered after the leachate interaction which affects the performance of the clay liner.

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 yield the most economical soil-bentonite mixture to build clay liners in arid zone.

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.

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