LOCALLY AVAILABLE EXPANSIVE SOILS AS A LINER MATERIAL FOR MUNICIPAL LANDFILLS

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Field Cod

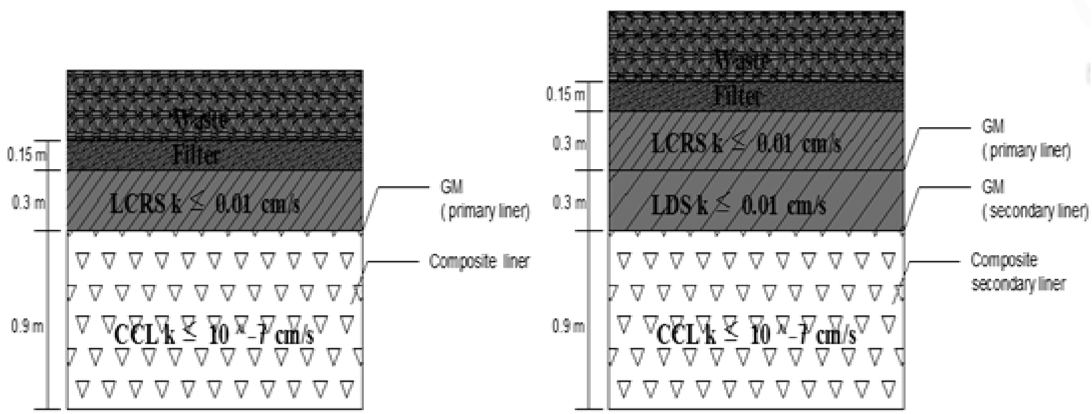
Abstract

The bottom liners in the municipal landfill sites are expected to prevent the migration of pollutants (leachate) to the groundwater. Different types of liner materials are being used in the construction of liners of municipal landfills over the world. Compared to the liner materials such as Geosynthetic Clay Liners (GCL) and High Density Polyethythene (HDPE), Compacted Clay Liners (CCL) are more economical, if materials are locally available. Different types of clay have been experimented for their suitability as liner materials in many countries. An expansive soil however, having a high plasticity index can be expected to absorb more volume of water emanating from the leachate and as a result it can withstand longer dry periods before cracks develop. Further, even if cracks do develop during a prolonged dry period, the cracks may self heal with the subsequent exposure to a rainy period as the shrink-swell behavior of expansive soils is reversible. Therefore, in this study, the suitability of a locally available expansive soils in which the major clay mineral is montmorillonite was investigated for use in landfill liners. For this purpose expansive soils obtained from Digana and Moragahakanda areas of Sri Lanka were chosen as candidate soils. The Rowe Cell apparatus was used to measure the hydraulic conductivity of the consolidated soil sample using de-aired water as the permeant liquid. The results showed that for all the test specimens hydraulic conductivity was less than 1x 10^{-9} m/s conforming to the requirements of maximum hydraulic conductivity recommended for liner materials. Similar tests were performed on expansive soils obtained from Moragahakanda amended by the addition of 5% bentonite (Sodium Bentonite). Addition of bentonite resulted in a decrease of hydraulic conductivity by a significant amount. Therefore, it can be concluded that subjected to the satisfaction of durability criteria the expansive soils of Digana and Moragahakanda are suitable as liner materials and have the potential to be incorporated into a relatively thin liner by amending with bentonite.

Key words: Liner materials, Expansive Soil, Hydraulic Conductivity, Bentonite, Rowe Cell Apparatus

1. Introduction

With the increasingly affluent life styles and development of industrial and commercial activities, a rapid increase of solid waste generation in most of the developing countries can be observed. Therefore, nowadays most of the countries try to use sanitary landfills to manage municipal solid waste (MSW). Although, the use of sanitary landfills has many advantages, generation of leachate which is highly contaminated from organic matter, inorganic matter, heavy metals, and xenobiotic organic compounds, if released into the environment untreated, poses severe environmental problems. Leachate is defined as the aqueous effluent generated as a consequence of percolation of rain water through waste, biochemical processes in waste's cell and the inherent water content of the waste themselves (Renou et. al., 2007). If there is no proper liner and a leachate collection system installed at the bottom of the landfill, the leachate can migrate into the groundwater leading to pollution of the water resource. The use of engineered landfills with a single or composite liner protects the surrounding environment including soil, surface water and ground water by against contamination. (USEPA, 1991).



(a) (b)

Figure 1: Example of liner systems: for (a) MSW landfills, and (b) hazardous waste landfill (LDS – Leakage Detection System, LCRS – Leakage Collection and Removal System)

Depending on the type of landfill (i.e. non-hazardous, hazardous or inert) the requirements of the lining system vary. Typical sections of composite landfill liners which can be used for municipal landfills and hazardous waste landfills are illustrated in Figure 1 (Assessment and Recommendations for improving the performance of waste containment facilities, US EPA, 2002). In order to satisfy the liner requirement for different types of landfills, either a single liner or a composite liner can be used. Other than the Compacted Clay liners (CCL), different types of liner materials such as Geosynthetic Clay liners (GCL) and High Density Polyethylene (HDPE) are also being widely used for the landfill bottom liners. However, under local conditions the construction cost of using these synthetic liner materials is exorbitant due to non-existence of local industry producing such materials. Further, these materials are subject to degradation affecting proper functionality as a liner material.

Compacted Clay Liners (CCL) are widely used as a liner, as the construction cost is less compared to the other liner systems, if the clays are locally available. In engineered landfills, the clay liner is designed not only to be of low hydraulic conductivity, but also to have sufficient structural stability to support itself and overlying components. Many engineering organizations and regulatory agencies recommend 1 x 10^{-9} m/s as the maximum allowable hydraulic conductivity for CCL (US EPA, 1991). There are number of criteria available for selecting suitable materials for a CCL, such as plasticity index, clay content etc. However, the hydraulic conductivity appears to be the most heavily weighted criterion which determines its performance. At the initial stage, index properties of soil such as particle size distribution, Atterberg limits can be used to identify and reject undesirable materials.

Instead of clays used in CCL, it is also possible to use expansive soils to develop a liner conforming to the liner requirements. In contrast, use of an expansive soil is more advantageous due to its very low hydraulic conductivity and its ability to retain more water due to its very high plasticity index and more importantly its self healing ability to seal off the cracks developed during an extremely long dry period. Characteristic expansive or swelling clays are highly plastic clays and they often contain colloidal clay minerals such as montmorillonite. Very small particle size, large internal surface area, diffuse negative layer charge allow montmorillonite clay mineral to absorb large amount of water. Therefore, if it is used to construct base liners, it can withstand longer dry periods without forming cracks.

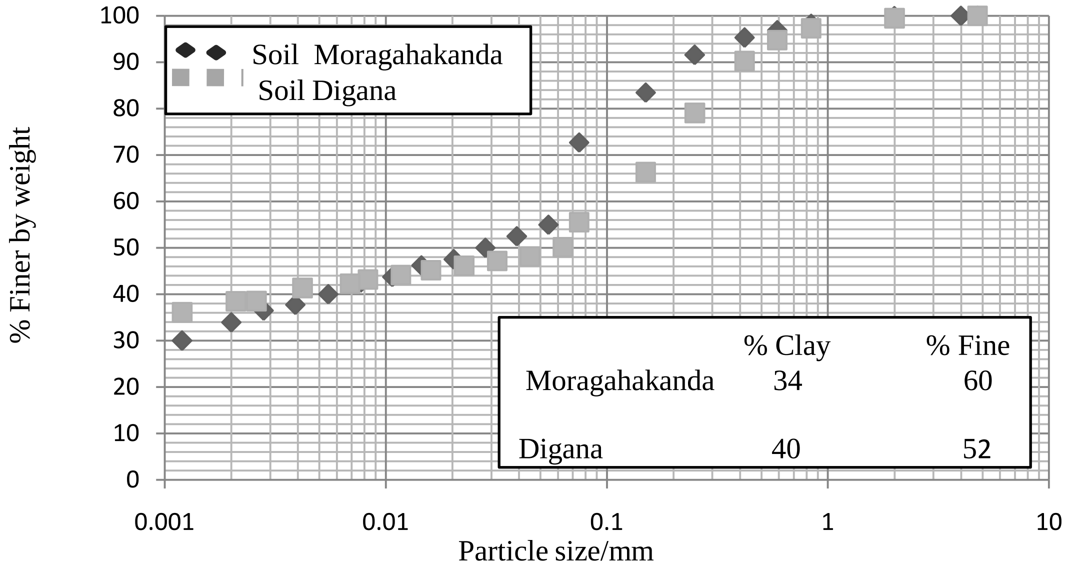


Figure 2*: Location map of sampling sites.*

In Geosynthetic Clay liners, bentonite is sandwiched between two geotextiles to facilitate low hydraulic conductivity. Bentonite is a natural montmorillonite rich clay formed by the transformation of volcanic ash. Use of soil- bentonite mixtures is also suggested as an economical alternative for constructing landfill liners for municipal landfill sites. The hydraulic conductivity of soil- bentonite mixtures depends on the percentage of bentonite added to the soil which in turn depends on the hydraulic conductivity characteristics of the soil.

Figure 3: Particle size distribution of soil obtained from Moragahakanda and Digana

2. Materials and Methods

2.1Materials

2.1.1 Expansive soil

Due to climatic and topographic factors, Sri Lanka has a wide variety of soil types. Both Digana and Moragahakanda are located in the central province of Sri Lanka. Both the soils are reddish brown clay and according to the most accepted soil classification system developed by United States Department of Agriculture (USDA) it is Rhodustalfs. Hereafter soil obtained from Moragahakanda and Digana will be referred as soil M and soil D respectively. Figure 2 shows the location of the above sampling sites. Disturbed soil samples were collected for carrying out soil classification, swelling pressure test, 1-D consolidation and hydraulic conductivity tests.

2.1.2 Bentonite

During this study, the hydraulic conductivity of soil obtained from Moragahakanda was evaluated after mixing with 5 w/w% of Sodium Bentonite (Bentofix®, NAUE GmbH & Co. KG, Germany). Liquid limit, plastic limit, specific gravity, particle size distribution, pH, electrical conductivity of the bentonite were evaluated following the British Standards. The results are given in Table 1. The Atterberg Limit test on bentonite was carried out taking care to cure the specimen for 24 hrs at each moisture content.

2.1.3 Permeant Liquids

In the initial stage de-aired water was used as the liquid used in consolidation and hydraulic conductivity tests.

Table 1: Index properties of bentonite

Property	*Value*
Liquid limit/%	*600*
Plastic limit/%	*55*
Plasticity Index	*545*
Specific Gravity	*2.68*
pH	*8.76 (1:10)*
Electrical Conductivity/(mS/cm)	*1.33*
Free swell index	*1600*

Property	*Soil*	
	Digana	*Moragahakanda*
Liquid limit/%	*50*	*44*
Plastic limit/%	*21*	*19*

Plasticity Index Ip	*29*	*25*
Swelling Pressure (kPa)	*40*	*126*
Specific Gravity	*2.74*	*2.64*
Soil pH	*-*	*8.06*
Electrical Conductivity (ms/cm)	*-*	*0.027*
Fine content/%	*52*	*60*
Clay content/%	*40*	*34*
Activity	*0.725*	*0.735*
Soil type	*Gravelly Clay of Intermittent Plasticity*	*Gravelly Clay of Intermittent Plasticity*
Potential swell/%	*2.91*	*4.40*

Table 2: Properties of soil obtained from Moragahakanda and Digana

2.2 Methods

2.2.1 Soil Classification

According to the US EPA guidelines for design of compacted clay liners, the liner material should satisfy certain requirements. Therefore, initially regular soil classification tests such as liquid limit, plastic limit, specific gravity, and particle size distribution were carried out to identify the soil properties. These tests were carried out conforming to those specified by ASTM and British Standards. 2. The particle size distribution of these two soils is given in Figure 3.

2.2.2 Swell classification

To identify the expansiveness of soil obtained from Moragahakanda and Digana, swell pressure test was carried out Other than the above test many criteria are available for swell classification based on Atterberg limits, percentage of free swell and activity. During this study liquid limit and plasticity index based swell classification according to IS 1498 (Indian Standard Classification and Soil Identification for General Engineering Purposes) and plasticity index and percentage of clay content based swell classification developed by Williams and Donaldson (1980) were used to identify the expansiveness of soil.

2.2.3 Consolidation and Hydraulic Conductivity Test

In modern landfills, waste heights over 50 m are becoming more common considering the difficulty in finding suitable sites and high volume of waste generated. Under such loads the investigation of compressibility characteristics of the compacted clay liners also becomes important. In order to evaluate the consolidation and hydraulic conductivity characteristics under different consolidation pressures, the Rowe cell apparatus (Rowe et. al., 1966) having a 15cm internal diameter was used. Rowe cell apparatus can be used to one dimensionally consolidate saturated soil, allowing drainage from both surfaces and then evaluate the hydraulic conductivity of the consolidated soil sample. In this consolidation cell, the total stress is applied by means of air pressure applied into a convoluted rubber membrane. In preparing the disturbed soil samples, de-aired water was added to the soil sieved through No. 200 standard test sieve (0.075 mm) in such a way that the amount of water added is 1.5 times the liquid limit of the soil. The soil was added to water through a sieve to facilitate better mixing which results in almost full saturation. Then, uniform slurry was obtained using a mechanical mixer. Then a vacuum pressure was applied to remove the air bubbles within the soil slurry. Finally, the slurry was poured into the Rowe cell and was allowed to settle for 24 hrs under its self weight.

Initially, the specimen was vertically consolidated up to a pressure of 50 kPa. Then, while keeping the applied consolidation pressure at the same value, the hydraulic conductivity of the consolidated sample was evaluated by allowing a steady seepage of water at a hydraulic head of 30, 50, 100,150 and 200 kPa. The above procedure of evaluating the hydraulic conductivity was repeated on the same sample after being reconsolidated under increased axial pressures.

In this study, the hydraulic conductivity was evaluated on the soil obtained from Moragahakanda consolidated under 50 kPa, 100 kPa and 200 kPa consolidation pressures and that obtained from Digana under 100 kPa, 200 kPa and 300 kPa. Also, the hydraulic conductivity of the soil obtained from Moragahakanda amended with 5 % of Sodium Bentonite by weight was evaluated using the same procedure that was followed for the Moragahakanda soil.

3. Results

3.1 Swell classification

According to liquid limit and plasticity index based swell classification criterion both soils obtained from Digana and Moragahakanda exhibit medium swelling capacity. But according to the activity based swell classification criterion both these soils have high expansiveness. It can be concluded that both the tested soils are expansive as the expansiveness of kaolinite rich clay is very low compared to these soil. (Taylor and Smith, 1986)

3.1 Compressibility characteristics

The relationship between void ratio and consolidation pressure are illustrated in Figure. 4. The variation of coefficient of consolidation (C_v), and coefficient of volume compressibility (m_v) with the applied pressure was evaluated using the Taylor's square root of time method. The results are illustrated in Figure 5 and Figure 6. For both soils obtained from Moragahakanda and Digana, it can be seen that the coefficient of consolidation increases with the increase of consolidation pressure. However, for the Moragahakanda soil mixed with 5% of bentonite, the coefficient of consolidation is considerably lower than the unamended soils and it decreases with the increase in pressure. This is in conformity with the observations of Robinson and Allam (1998). As expected coefficient of volume compressibility decreases with the increase of consolidation pressure for all soil types.

The compressibility of particular soil is governed by the mechanical properties of the soil grains and by the lubricating effect of the pore fluid. However, depending on the clay mineralogy, saturating cation and pore fluid, the compressibility of clays may be influenced by both mechanical and physicochemical effects. The compressibility of kaolinite and illite is controlled by the mechanical effects whereas physicochemical effects control the compressibility of montmorillonite rich clay (Robinson and Allam, 1998).

3.2 Hydraulic conductivity

According to the Darcy's law, under laminar flow conditions, the flow rate through a porous media is directly proportional to the applied hydraulic gradient, hydraulic conductivity being the constant of proportionality. The variation of hydraulic conductivity with the consolidation pressure is illustrated in Figure 7. With the increase of consolidation pressure, the hydraulic conductivity decreased for all three soils. The mixing of 5% bentonite with the soil obtained from Moragahakanda gave the lowest hydraulic conductivity among all three types of soil. Bentonite in the soil-bentonite mixtures hydrate and swell with the presence of water. Under fully saturated conditions, bentonite has very high swelling capacity and can be expected to fill the voids between the soil particles, reducing the hydraulic gradient.

According to the results of swell pressure test and swell classification based on the liquid limit and plasticity index, soil obtained from Moragahakanda exhibited higher swelling capacity compared to the soil obtained from Digana. The hydraulic conductivity of the soil obtained from Moragahakanda is lower than that of soil obtained from Digana. This can be explained by the higher expansiveness of soil obtained from Moragahakanda compared to the soil obtained from Digana.

The variation of hydraulic conductivity with void ratio is shown in Figure 8. The relationship between the hydraulic conductivity and the void ratio as given in eq.(1) is plotted in Figure 9.

$$K \propto \frac{e^3}{(1+e)} \qquad \text{Eq. (1)}$$

This shows good agreement of the variation of hydraulic conductivity with the void ratio in accordance with the Kozney-Carman equation for both unamended soils obtained from Digana and Moragahakanda while less agreement on bentonite amended soil. (Won-Jin Cho, 2002)

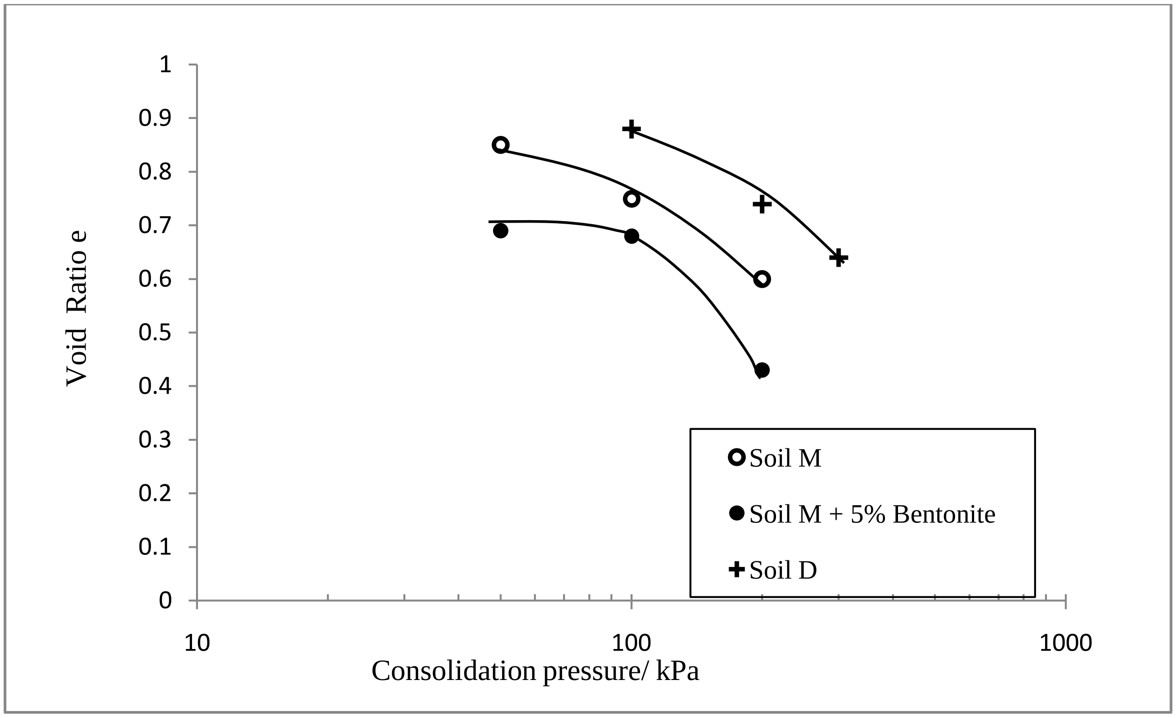


Figure 4: Variation of void ratio with consolidation pressure

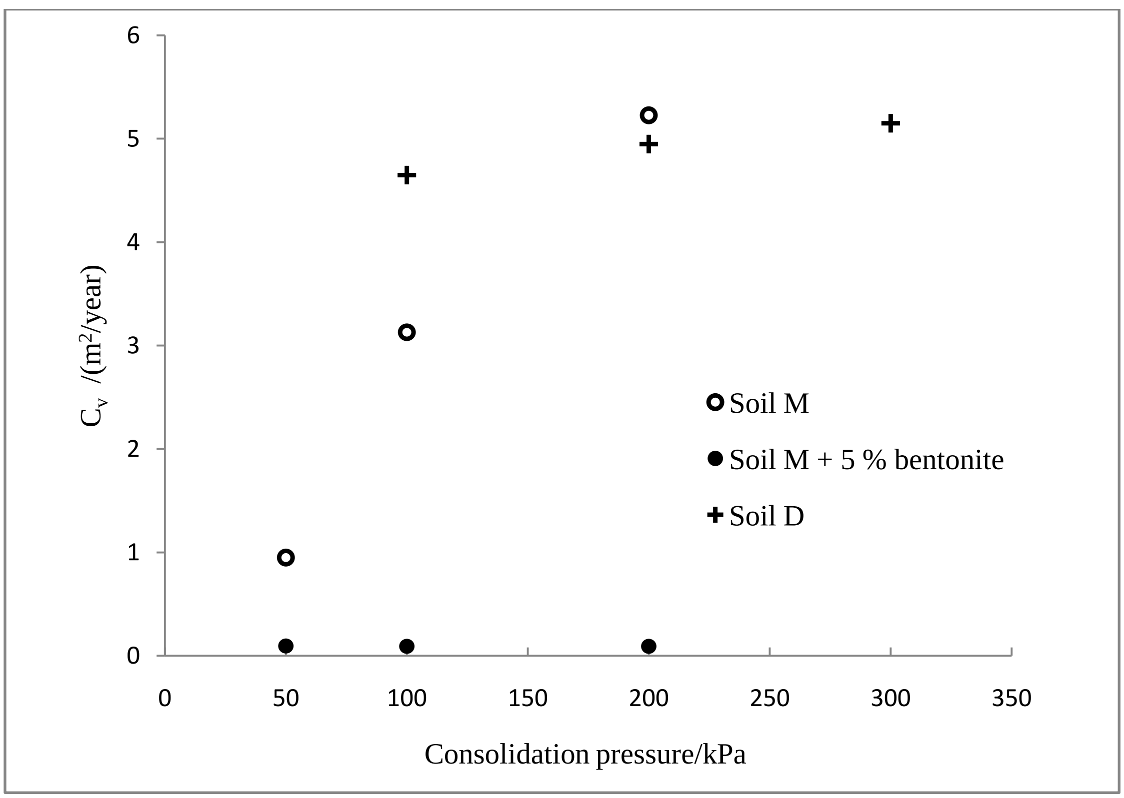


Figure 5: Variation of coefficient of compressibility with consolidation pressure

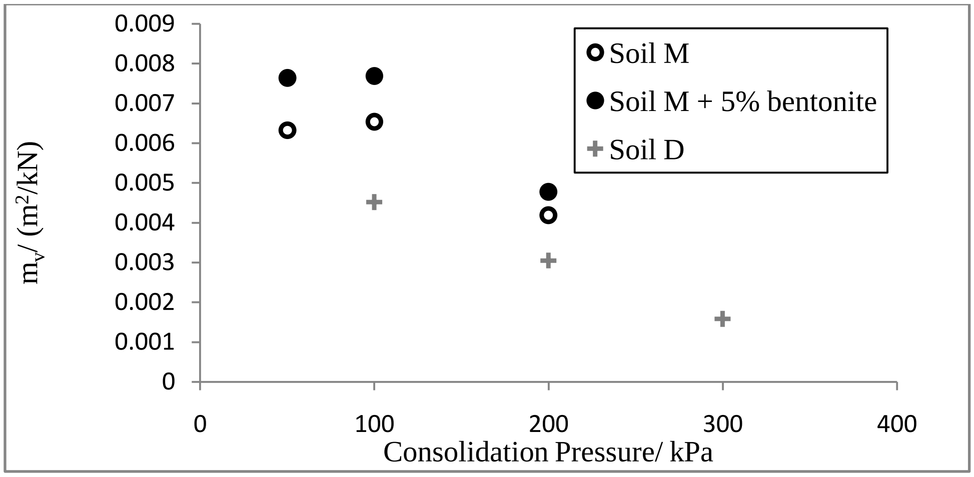


Figure 6: Variation of coefficient of volume compressibility with consolidation pressure.

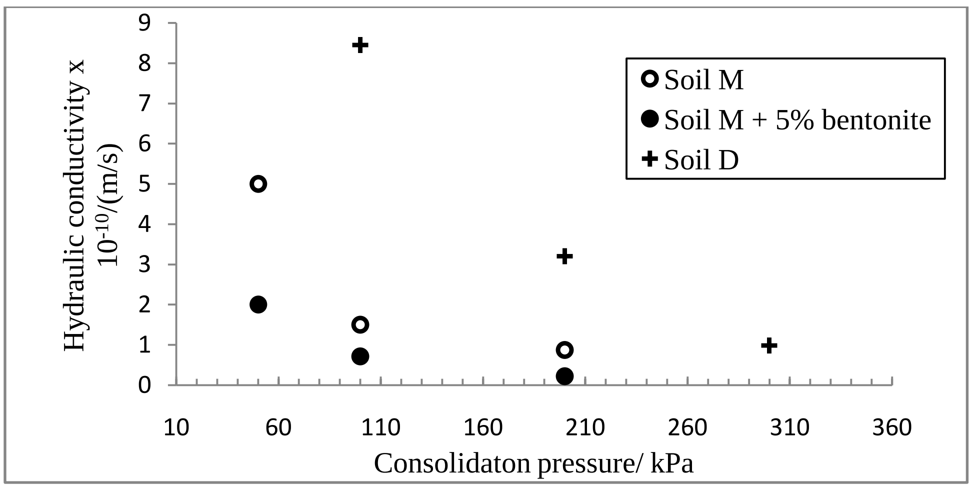


Figure 7: Variation of hydraulic conductivity with consolidation pressure.

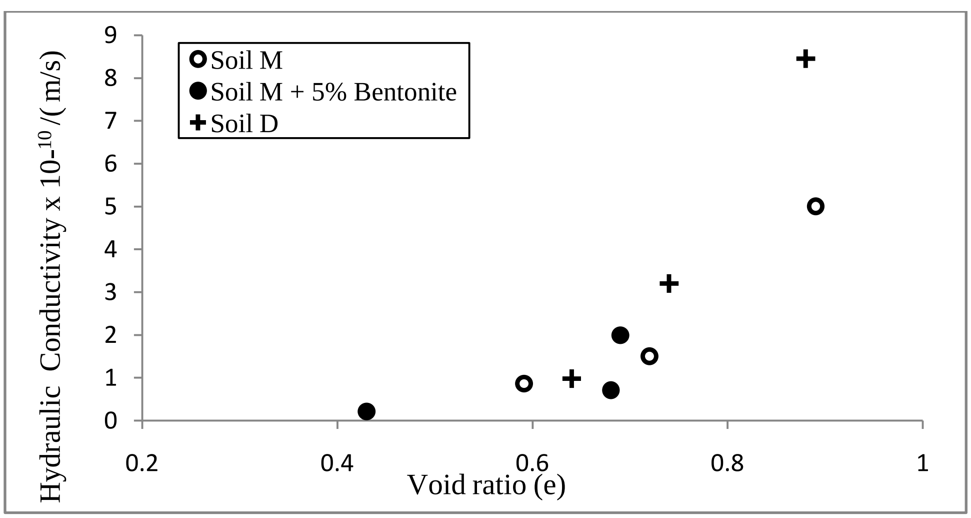


Figure 8: Variation of hydraulic conductivity with void ratio

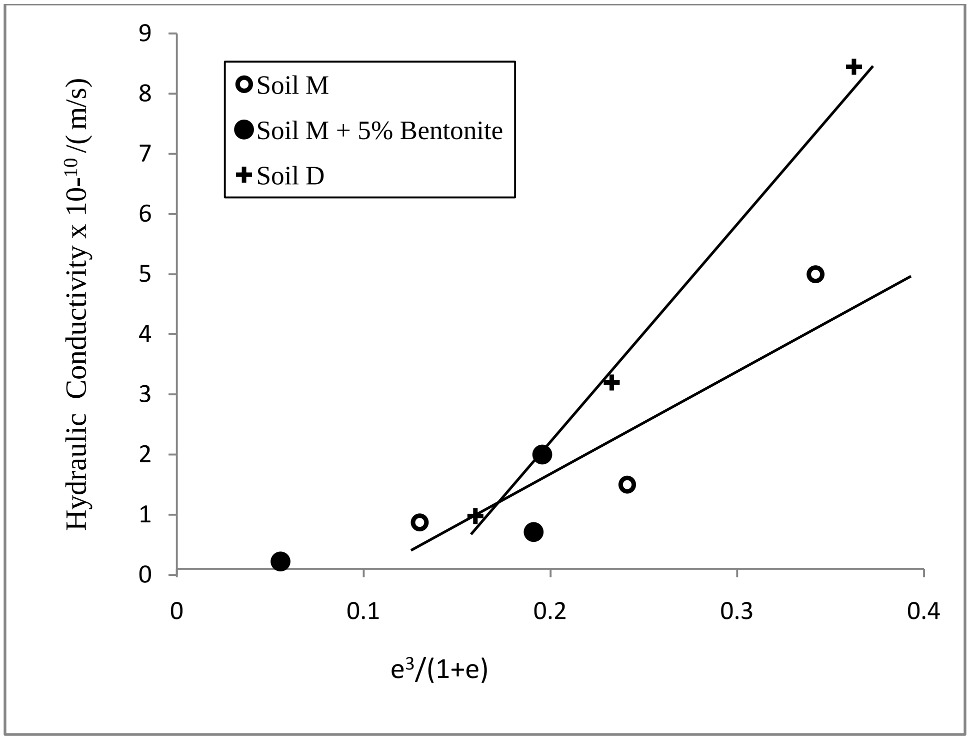


Figure 9: Relationship between hydraulic conductivity and $e^3/(1+e)$

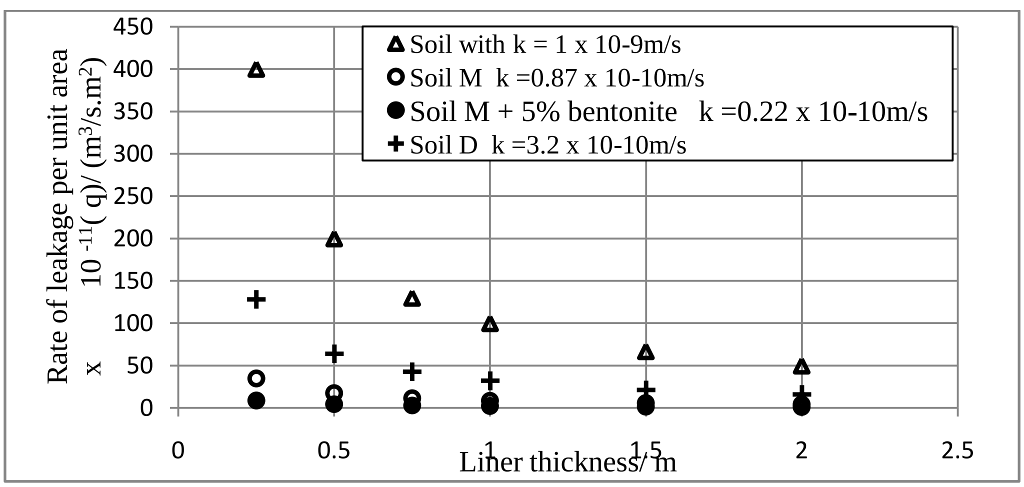


Figure 10: Variation of rate of leakage through a unit area of liner with liner thickness.

3.3 Practical implications

The recommended maximum hydraulic conductivity through a 1m thick compacted clay liner is 1 x 10^{-9} m/s. Alternatively, this criterion can also be expressed as the maximum allowable rate of leakage through the compacted clay liner, which can be used as a guideline to design an economical liner system which is equivalent to a 1 m thick liner system having a hydraulic conductivity of 1 x 10^{-9} m/s. However, the rate of leakage through a unit area of clay liner depends on the leachate head exerted on the clay liner. It is noted that the hydraulic conductivity of all the soils tested is less than the maximum recommended value.

However, the layer thickness of the compacted clay liner can be reduced using the clayey soils with much lower hydraulic conductivity. The variation of rate of leakage with clay liner thickness subjected to 1 m leachate head for the three types of soil used and that for the soil having the maximum hydraulic gradient of 1 x 10^{-9} m/s is illustrated in Figure 10 which gives an indication on the thickness of liner required.

4. Conclusions

Since both soil samples obtained from Digana and Moragahakanda exhibited lower hydraulic conductivity values than the maximum recommended, these soils can be satisfactorily used to construct compacted clay liners in municipal landfill sites.

Although, the mixing of 5% bentonite resulted in lower hydraulic conductivity than the unamended soil, the decrease of hydraulic conductivity is not significant, especially under high consolidation pressures. Therefore, tests should be carried out to evaluate the optimum percentage of bentonite which results in much lower hydraulic conductivity so that the clay liner thickness can be reduced accordingly. However, it is generally recognized that the mixing in the field requires more control than that required under laboratory conditions.

During this study de-aired water was used as the permeant liquid when evaluating the hydraulic conductivity. However, in practice, the liner is exposed to leachate which is highly contaminated from different organic and inorganic pollutants. Considering expansive soil and soil-bentonite mixtures for the construction of landfill liners, not only the mechanical properties but also physicochemical properties directly affect the hydraulic conductivity through the liner. Compared to the kaolinite rich clays, physicochemical properties are very much dominant for montmorillonite clays due to its higher cation exchange capacity and specific surface area. The physicochemical properties are very sensitive to the changes in pore fluid (Olson and Mesri, 1971). Therefore, the effect of interaction between clay and leachate on the hydraulic conductivity needs to be investigated for the sustainable use of the compacted clay liner.

Acknowledgments

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