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GEOTECHNICAL ASSESSMENT OF MALAYSIAN RESIDUAL SOILS FOR UTILIZATION AS CLAY LINERS IN ENGINEERED LANDFILLS

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ABSTRACT: Compacted natural soils are often used as liner materials in engineered landfills to minimize the environmental impacts attributed to landfills by preventing the migration of leachate and landfill gases into the environment and groundwater. Numerous researchers have assessed the suitability of typical Malaysian residual soils as clay liners in an engineered landfill. However, previous studies evaluated their suitability for liner application using just tap water as the saturating and permeating fluids, which is far from being representative of the field conditions. Hence, this study aimed at evaluating the suitability of two residual soil deposits of Kenny Hill rock formation as liner materials in engineered landfills by conducting a series of geotechnical tests using both tap water and municipal solid wastes leachate as saturating and permeating fluids. Results of the study indicated that soil A complied with all the requirements for liner utilization in terms of fines content, plasticity index, hydraulic conductivity, and unconfined compressive strength (UCS). On the other hand, soil B failed to meet the requirements in terms of fines content and UCS. When leachate was used as permeating fluid, there was a reduction in the hydraulic conductivity of both soil samples. Nonetheless, increased UCS and reduced Atterberg limit were observed for both soil samples when saturated with leachate. Based on the results, it is fair to conclude that soil A is more suitable for liner utilization relative to soil B.

Keywords: Clay liners; Landfill; Leachate; Residual soils; Geotechnical properties

1. INTRODUCTION

In Malaysia, government effort on waste management was not palpable until the late 1970s when solid waste management began with street cleaning and domestic waste transportation to disposal sites [1]. The management of solid waste then was quite primitive and suited to cater only to the daily municipal solid waste (MSW) generated, and was estimated at about 0.5kg per capita [2]. Moreover, the system of the waste collection was only confined to urban areas while the rural communities disposed of by burying or burning within their compounds [3]. Besides, disposal sites then were mere open-dumping grounds with small sizes corresponding to the small communities and were preserved by the local authorities [4].

With the growth in economic development, urbanization, industrialization, population, and improvement in the standard of living, the quantity of waste produced has rapidly increased in recent years with an average daily per capita generation of 1.2kg in 2007 and greater than 1.7kg in 2010 [1], thus making the management of MSW one of Malaysia’s most critical environmental issues. As a result, the solid waste management system (SWMS) was required to be upgraded to suit the waste quantity and composition.

Typical SWMS techniques employed to curtail menace of the generated wastes includes; incineration, well injection, reuse, recycling, composting and among others. Despite these advancements in solid waste management technologies to minimize the environmental impacts attributed to the waste, a safe disposal facility was still necessary for the disposal of the final and/or unusable waste. Therefore, municipal authorities were compelled to impound these wastes behind specially designed engineered landfills that utilize bottom liner systems. Bottom liners are primarily used to prevent the migration of leachate and landfill gases from the landfill into the surrounding environment and groundwater, hence, protecting the environment and groundwater from pollution.

Geosynthetic clay liners, geomembranes, and natural soils are commonly used as landfill liners. These liners have their unique advantages and disadvantages over their counterparts. The pros and cons of geosynthetic clay liners are extensively discussed by [5]. On the other hand, the merits of natural soils for liner utilization have been examined by several researchers [6-9] and they include but not limited to; they are naturally occurring and readily available, relatively inexpensive when on site or in close proximity, less vulnerable to mechanical accidents (punctures), good compatibility with the permeating fluid and high attenuation capacity, etc.

Various naturally occurring geomaterials have been evaluated for their suitability as liner materials in engineered landfills in Malaysia. For instance, [9] investigated the potential of marine clay obtained from Kedah as landfill liners. Taha and Kabir [10] studied the suitability of granite residual soils obtained from a granitic formation at Cheras for their application as liner materials. Taha and Kabir [11] evaluated the potential of sedimentary residual soils as hydraulic barriers in waste containment systems. Zulkifli, Wong, Alia, Ridzuan and Zawawi [12] studied the properties of natural soil from Endau Rompin National Park as compacted soil liner for sanitary landfills. Nik, Mazidah, Soenita and Norazlan [13] investigated the properties of blended lateritic soils for designing soil liners. However, very little is known about the potential of Subang and Putrajaya residual soils for use as hydraulic barriers in engineered landfills. Moreover, previous studies evaluated the suitability of residual soils for liner application using tap water as the saturating and permeating fluid which is far from being representative of the field conditions. Thus, this study aimed at assessing the geotechnical properties of two Malaysian residual soils which occur in considerable quantities for their usability as liner materials in engineered landfills. Their suitability was investigated using both tap water and MSW leachate as the saturating and permeating fluids.

2. MATERIALS AND METHODS

2.1 Residual Soils

The residual soils used in this study were obtained from Subang and Putrajaya, Malaysia for soil sample A and B, respectively as depicted in Fig.1. The soils were sampled from a 3m depth below the ground surface. The obtained samples bagged, labeled, and transported to the soil laboratory for analysis. The soils in both areas result from the weathering of the Kenny Hill rock formation consisting of interbedded sandstone, siltstone and shale [14].

The soil samples were oven-dried for 3 days at 105ºC. The dried samples were then crushed and sieved to an appropriate size before testing. The pulverized soil samples were subjected to geotechnical tests by using tap water and MSW leachate as saturating and permeating fluids (referred to as soil-water and soil-leachate samples). Various geotechnical properties of the soils including particle size distribution (PSD), Atterberg limits and specific gravity were conducted according to standard procedures outlined in [15]. The soil samples passing through sieve number 4 (4.75mm) were further subjected to compaction, hydraulic conductivity, and unconfined compressive strength (UCS) tests. The compaction characteristics were evaluated by utilizing the standard Proctor compaction method as stipulated in [15]. The UCS test was conducted according to standard procedures outlined in [16] with an applied rate of strain of 1% per minute. The hydraulic conductivity was measured by employing the falling head technique in accordance with standard procedures presented in [17].

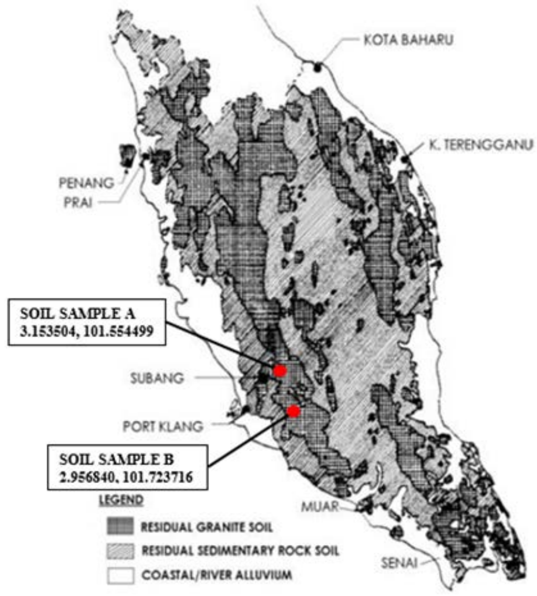

Fig. 1 Map of Peninsular Malaysia showing the distribution of residual soils (Modified after Ooi, 1982) [18].

2.2 Municipal Solid Wastes (MSW) Leachate

MSW leachate used in the study was collected from the Taman Beringin Transfer Station. The collected leachate sample was stored in a refrigerator at a temperature of 4°C to minimize any chemical and biological reactions before testing. The physicochemical composition of the leachate as obtained from ALS Technichem (M) Sdn Bhd, Malaysia is presented in Table 1.

3. RESULTS AND DISCUSSIONS

3.1 Soil Classification and Properties

The soil samples were classified based on their silica-sesquioxide ratio (SSR). The silica-sesquioxide ratio differentiates soil types by their degree of weathering based on their metal oxides as shown in Eq. (1) [19].

$$SSR = \frac{SiO_2 / 60}{(Al_2O_3 / 102) + (Fe_2O_3 / 160)} \quad (1)$$

Table 1 Physico-chemical composition of the leachate.

Parameters	Concentration
Physical and Aggregate Properties	
Total Dissolved Solids (mg/L)	9660
Total Hardness as $CaCO_3$ (mg/L)	1900
pH	3.57
Electrical Conductivity (mS/cm)	12.61
Inorganic and Nonmetallic Properties (mg/L)	
Chloride	2370
Sulphate	497
Metals and Major Cations (mg/L)	
Cadmium	0.02
Chromium	0.49
Copper	0.39
Iron	369
Lead	0.08
Manganese	5.11
Nickel	0.36
Zinc	6.10
Environmental Quality (mg/L)	
Biological Oxygen Demand	23800
Chemical Oxygen Demand	61200
Total Suspended Solids	12000
Ammonia as N	462

Table 2 Metal oxides of the residual soil samples.

Metal Oxides (%)	Soil Samples	
	A	B
Al_2O_3	28.683	30.213
SiO_2	55.350	27.868
Fe_2O_3	5.928	24.715
Silica-sesquioxide ratio, SSR (%)	2.90	1.03

Note : SSR < 2.0 is intensely weathered ferralitic soil whereas SSR > 2.0 is less intensely weathered ferruginous soil [19].

From the above relationship, soil sample A can be classified as a ferruginous soil (SSR=2.9) while soil sample B is classified as a ferralitic soil (SSR=1.03).

The geotechnical properties of soil samples are summarized in Table 3 and their corresponding grading curves presented in Fig.2. From Fig.2, it is observed that the dominant particle size of soil A is sand (69.25%), followed by clay fraction (15%), silt (13.9%), and gravel (1.85%). Soil B contains 84.1% of a sand-sized fraction, 10.03% of a silt-sized fraction, and 5.87% of the clay-sized fraction. Daniel [20] and Benson and Trast [21] suggested the following requirements for soil liner materials: percentage of gravels ≤ 30%, a percentage of fines ≥ 20-30%, and percentage of clay ≥ 15%. Based on the stated requirements, the grading characteristics of soil A fulfilled the requirements of landfill liner utilization. However, the percentage of fines and clay fractions presented in soil B did not meet the aforementioned requirements.

The plasticity index of soil A and B are 28.30% and 36.50%, respectively. The obtained plasticity index for both soil samples met the plasticity index criteria of ≥ 7% for liner utilization as recommended by [20] and [21]. Soil sample A and B are classified as inorganic clay of high plasticity (CH) and silt of high plasticity (MH) respectively in accordance with the unified soil classification system (USCS). Soil-leachate samples recorded a lower liquid limit (46.20% and 57.80%) and plasticity indices (27.20% and 32.04%) relative to soil-water samples (liquid limits 50.10% and 73%, plastic indices 28.30% and 36.50%). This reduction in Atterberg limits is attributed to the increased concentration of multivalent cations in the leachate that resulted in the reduction of diffusive double layer (DDL) thickness of soil, consequently leading to an increased amount of free water in the system [22,23]. Similar findings have been reported by [24-26].

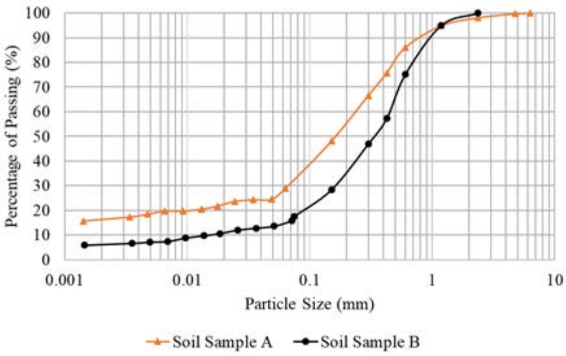

Fig. 2 Grading curves for residual soil samples.

3.2 Compaction Properties

Soil compaction is normally performed to break down the soil chunk into a homogenous mass that results in increased soil density and strength and reduced hydraulic conductivity. The moisture-density relationship for both soils is shown in Table 3 and Fig. 3. Soil-leachate samples experienced a reduction in optimum moisture content and increment in MDD compared to soil-water samples as observed from Table 3. The variation in the compaction characteristics of the soil-water and soil-leachate samples are due to the chemical interaction of leachate with soil particles, resulting in the attraction of soil particles and hence, denser soil structure. The findings are consistent with that reported by [27]. However, the differences between the optimum moisture content and MDD for soil-water and soil-leachate samples are minimal. Hence, it can be concluded that leachate has no significant effect on the compaction properties of both soil samples. The obtained MDD values suggest that adequate compaction can be obtained when both soils are utilized as liner materials in engineered landfills.

Table 3 Geotechnical properties of the residual soil samples.

Properties	Soil –water Sample		Soil-leachate Sample	
	A	B	A	B
Particle Size Distribution, %				
Gravel	1.85	0	-	-
Sand	69.25	84.10	-	-
Silt	13.90	10.03	-	-
Clay	15.00	5.87	-	-
Fines Fraction	28.90	15.90	-	-
Specific Gravity, Gs	2.70	2.84	-	-
Atterberg Limit, %				
Liquid Limit , w_L	50.10	73.00	46.20	57.80
Plastic Limit , w_P	21.80	36.50	19.00	25.76
Plasticity Index , I_p	28.30	36.50	27.20	32.04
Max. Dry Density , ρ_{dry} (kN/m^3)	17.25	14.95	17.30	15.00
Optimum Moisture Content, W_{opt} (%)	18.00	30.50	17.50	29.00
Hydraulic Conductivity (cm/s)	3.927×10^{-8}	1.202×10^{-7}	3.448×10^{-8}	1.461×10^{-8}
Unconfined Compressive Strength (kPa)	383.34	164.10	453.75	231.50

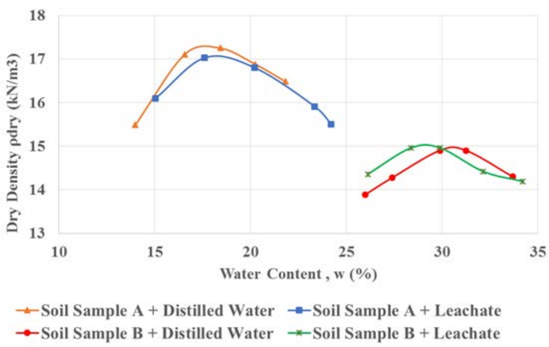

Fig. 3 Compaction curves for both soils saturated with tap water and leachate.

3.3 Hydraulic Conductivity

The hydraulic conductivity of soils A and B after permeation with tap water were found to be 3.927×10^{-8}cm/s and 1.202×10^{-7}cm/s respectively. After leachate permeation, the hydraulic conductivities for both soils A and B reduced to 3.448×10^{-8}cm/s and 1.461×10^{-8}cm/s respectively. The reduction in the hydraulic conductivity could be due to the presence of suspended particles and microorganism from the leachate that caused the pore of the soils to clog, and consequently, a reduction in the hydraulic conductivity was observed [28]. Similar findings were reported by [24,26,28]. The measured hydraulic conductivities for both soils are within the specification for soil liner utilization of less than 1×10^{-6}cm/s [29]. The low hydraulic conductivity recorded for soil A in comparison to soil B is due to the higher percentage of fines fraction present in soil A (28.90%) compared to soil B (15.90%).

3.4 Unconfined Compressive Strength (UCS)

The stress-strain relationship of the soil-water and soil-leachate samples are presented in Fig. 4. From Fig. 4, it can be observed that the UCS for soil A showed an increment from 383.34kPa to 453.75kPa after leachate application. Similarly, the UCS value for soil B increased from 164.1kPa to 231.5kPa after leachate application. This increment in UCS is associated with the decreased DDL thickness of soil-leachate samples that contributed to a denser soil structure due to soil particles attraction [30]. Daniel and Wu [31] recommended a minimum UCS of 200kPa for soil liner materials. The UCS of soil A for both types of saturation fluids met the requirement for liner utilization whereas for soil B saturated with tap water failed to meet the strength requirement.

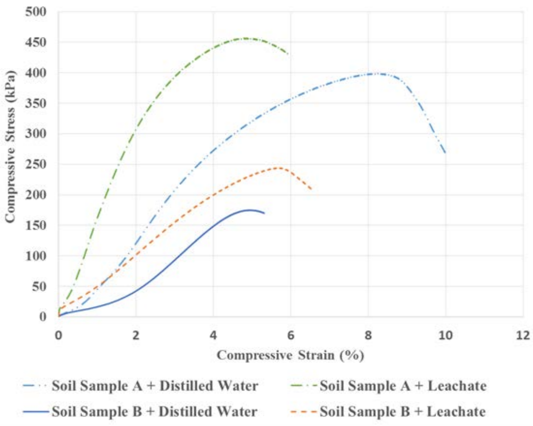

Fig. 4 Compressive stress-strain curves for both soils saturated with tap water and leachate.

4. CONCLUSIONS

Two tropical residual soils from Kenny Hill rock formation were evaluated for their suitability as compacted soil liner material in engineered landfills by conducting a series of geotechnical tests using both tap water and MSW leachate as permeating and saturating fluids. Based on the results, the following conclusions can be drawn:

1. Soil A fulfilled all the requirements of grading characteristics for landfill liner materials while soil B failed to meet the requirements in terms of fines content and UCS.
2. The plasticity indices of both soils sample A and B fulfilled the requirement for liner utilization. After leachate application on both soil samples, it was observed that their Atterberg limits decreased due to the reduction in the thickness of DDL which caused an increased amount of free water in the system.
3. Soil-leachate interaction contributed to the formation of denser soil structure and hence, caused some variations in compaction characteristics of both soils. However, the differences in the compaction properties of soil-water and soil-leachate samples are minimal.
4. The hydraulic conductivities for both soil-water and soil-leachate samples satisfied the specification for soil liner utilization. The reduction in hydraulic conductivities of soil-leachate samples is attributed to physical and biological clogging of soil pores due to the presence of suspended particles and microorganism from the leachate.
5. The UCS of soil A saturated with tap water and leachate fulfilled the strength requirement for liner utilization whereas for soil B saturated with tap water failed to meet the strength requirement. The UCS of both soil-leachate samples increased due to the formation of a denser soil structure resulting from the decreased DDL thickness.
6. Soil sample A is considered as a potential material for landfill liner compared to soil sample B. Soil sample B may require soil stabilization to improve their properties before utilizing as landfill liner materials.

5. ACKNOWLEDGMENTS

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6. REFERENCES

[1] Fauziah S. H. and Agamuthu P., Landfills in Malaysia: Past, Present, and Future, 1st Int. Conf. on Final Sinks, 2010, pp. 1-9.

[2] Perithamby A., Hamid S.F. and Khidzir K., Evolution of Solid Waste Management in Malaysia: Impacts and Implications of the Solid Waste Bill 2007, Journal of Material Cycles and Waste Management, Vol 11, Issue 2, 2009, pp. 96–103.

[3] Fauziah S. H. and Agamuthu P., Trends in Sustainable Landfilling in Malaysia, a Developing Country, Waste Management and Research, Vol 30, Issue 7, 2012, pp. 656–663.

[4] Latifah A. M., Mohd A. A. S. and Nur I. M. Z., Municipal Solid Waste Management in Malaysia: Practices and Challenges, Waste Management, Vol 29, Issue 11, 2009, pp. 2902–2906.

[5] Bouazza A., Geosynthetic Clay Liners, Review Article, Geotextiles and Geomembranes, Vol 20, No. 1, 2002, pp. 3-17.

[6] Manoj K. and DK. S., A Study on the Technique to Improve Desiccation Cracks, International Journal of Research in Advanced Engineering and Technology, Vol 1, No. 3, 2015, pp. 24-26.

[7] Akayuli C. F. A., Gidigasu S. S. R. and Gawu S. K.Y., Geotechnical Evaluation of a Ghanaian Black Cotton Soil for use as Clay Liner in Tailings Dam Construction, Ghana Mining Journal, Vol 14, 2013, pp. 21-26.

[8] Preeti S. A. and Singh B. K., Instrumental Characterization of Clay by XRD, XRF, and FTIR, Indian Academy of Science, Vol 30. No. 3, 2007, pp. 235-238.

[9] Rahman Z. A., Yaacob W. Z. W., Rahim S. A., Lihan T., Idris W. M. R. and Mohd W. N. F., Geotechnical Characterization of Marine Clay as Potential Liner Material, Sains Malaysiana,

Vol 42, No. 8, 2013, pp. 1081–1089.
[10] Taha M. R. and Kabir M. H., Tropical Residual Soil as Compacted Soil Liners, Environmental Geology, Vol 47, No. 3, 2005, pp. 375–381.
[11] Taha M. R. and Kabir M. H., Sedimentary Residual Soils as a Hydraulic Barrier in Waste Containment Systems, In Proceedings of the 2nd International Conference on Advances in Soft Soil Engineering Technology Putrajaya, Malaysia, 2003, pp. 895-904.
[12] Zulkifli A., Wong M. S., Alia D., Ridzuan M. B. and Zawawi D., Study on the Natural Soil Properties of Endau Rompin National Park (PETA) as Compacted Soil Liner for Sanitary Landfill, International Journal of Integrated Engineering, Vol 5, No. 1, 2013, pp. 14–16.
[13] Nik N. S., Mazidah M., Soenita H. and Norazlan K., Influence of Compaction Effort for Laterite Soil Mix with Geopolymer in Designing Soil Liner, Electronic Journal of Geotechnical Engineering, Vol 20, No. 22, 2015, pp. 12353–12364.
[14] Mohamed Z, Rafek A.G. and Komoo I., Characterisation and Classification of the Physical Deterioration of Tropically Weathered Kenny Hill Rock for Civil Works, Electronic Journal of Geotechnical Engineering, Vol 12, 2007, pp. 1-16.
[15] British Standard Institution 1377, Methods of Test for Soils for Civil Engineering Purposes, 1990, pp. 1-142.
[16] American Society for Testing and Materials D2166, Standard Test Method for Unconfined Compressive Strength of Cohesive Soil, 2005, pp. 1-6.
[17] American Society for Testing and Materials D5856, Standard Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-wall, Compaction-Mold Permeameter, 2007, pp. 1-8.
[18] Huat B.K.,Gue S.S. and Ali F.H., Country Case Study: Engineering Geology of Tropical Residual Soils in Malaysia, Tropical Residual Soils Engineering. 2nd ed. Taylor and Francis Group, London, UK, 2009, pp. 418-431.
[19] Engineering Group of the Geological Society, Working Party Report, Quarterly Journal of Engineering Geology and Hydrogeology, Vol 23, No 4-101, 1990, pp. 1-98.
[20] Daniel D.E., Clay Liners, Geotechnical Practice for Waste Disposal, 1st ed, Chapman and Hall, UK,1993, pp. 137-163.
[21] Benson, C.H. and Trast J.M., Hydraulic conductivity of thirteen compacted clays, Clays and Clay Minerals, Vol 43, No. 6, 1995, pp. 669-681.
[22] Mitchell J.K. and Soga K., Soil-Water-Chemical Interactions, Fundamentals of Soil Behavior, 3rd ed., John Wiley & Sons, Canada, 2005, pp. 143-171.
[23] Othman M.Z. and Shafii F, The Effects of Electrolytes on Liquid Limit of Clay, Journal of Civil Engineering, Vol 11(1), 1998, pp. 7-19.
[24] Frempong E.M. and Yanful E.K., Interactions between Three Tropical Soils and Municipal Soild Waste Landfill Leachate, Journal of Geotechnical and Geoenvironmental Engineering, Vol 134, No.3, pp. 379-396.
[25] Harun S.N., Ali Rahman Z., Rahim S.A., Lihan T. and Idris W.M.R., Effects of Leachate on Geotechnical Characteristics of Sandy Clay Soil, AIP Conference Proceedings, Vol 1571, No.1, 2014, pp. 530-536.
[26] Yantrapalli S., P.Krishna Hari and K Srinivas, A Study on Influence of Real Municipal Solid Waste on Properties of Soils in Warangal, India, Journal of Geoscience, Engineering, Environment and Technology, Vol 3, No. 1, 2018, pp. 25-29.
[27] Nayak S., Sunil B.M., and Shrihari S., Hydraulic and Compaction Characteristics of Leachate-contaminated Lateritic Soil, Engineering Geology, V.94, 2007, pp.137-144.
[28] Francisca F.M. and Glatstein, Long Term Hydraulic Conductivity of Compacted Soils Permeated with Landfill Leachate, Applied Clay Science, Vol 49, 2010, pp. 187-193.
[29] Ministry of Housing and Local Government Malaysia, The Technical Guideline for Sanitary Landfill, Design and Operation (Revised Draft), 2004, pp. 1-222.
[30] George M., Studies on Landfill Leachate Transportation and Its Impact on Soil Characteristics. Doctor of Philosophy, Cochin University of Science and Technology, 2014, pp. 1-229.
[31] Daniel D. E., and Wu. Y. K., Compacted Clay Liners and Covers of Arid Sites, Journal of Geotechnical Engineering, Vol 199, No. 2, 1993, pp. 223-237.

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