

PAPER • OPEN ACCESS

## Soil water characteristic curves for laterite soil at different water contents and methods as lining system

To cite this article: Yamusa Bello Yamusa *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **527** 012002

View the [article online](#) for updates and enhancements.

### Recent citations

- [Stability of Railway Embankment in Saturated and Unsaturated Conditions](#)  
M J Roshan *et al*



**The Electrochemical Society**

Advancing solid state & electrochemical science & technology

The ECS is seeking candidates to serve as the

**Founding Editor-in-Chief (EIC) of ECS Sensors Plus,**

a journal in the process of being launched in 2021

The goal of ECS Sensors Plus, as a one-stop shop journal for sensors, is to advance the fundamental science and understanding of sensors and detection technologies for efficient monitoring and control of industrial processes and the environment, and improving quality of life and human health.

*Nomination submission begins: May 18, 2021*



## Soil water characteristic curves for laterite soil at different water contents and methods as lining system

Yamusa Bello Yamusa<sup>1,2</sup>, Muhammad Azril Hezmi<sup>1</sup>, Kamarudin Ahmad<sup>1\*</sup>, Khairul Anuar Kassim<sup>1</sup>, Radzuan Sa'ari<sup>1</sup>, Noraliani Alias<sup>1</sup>, Mushairry Mustaffar<sup>1</sup>, Azman Kassim<sup>1</sup>, Ahmad Safuan A. Rashid<sup>1</sup>

<sup>1</sup>Faculty of Engineering, School of Civil Engineering, Universiti Teknologi Malaysia, 81310 Johor Bahru, Johor, Malaysia

<sup>2</sup>Department of Civil Engineering, Nuhu Bamalli Polytechnic, 810001 Zaria, Nigeria

\*Corresponding e-mail: kamarudin@utm.my

**Abstract.** Preventing groundwater contamination from the most common method of solid waste disposal technique i.e. landfilling is by proving hydraulic barriers. Accordingly, water movement in unsaturated soil is important in the analysis of leachate migration in soil material used as hydraulic barrier in waste containment systems. A full-scale experiment would be prohibitively costly and time consuming. The only feasible recourse therefore is to construct a model, which reasonably portray the behaviour of the full-scale system and simulate the relevant physical parameters and describes the overall significant characteristics of the transport phenomena. This paper presents the trends and patterns of soil water characteristic curves (SWCC) in terms of volumetric water content versus soil suction developed for compacted laterite soil specimens using data from pressure plate tests. Specimens were prepared at three different water contents corresponding to dry of optimum, optimum, and wet of optimum conditions. Models suggested by Brooks and Corey (BC), van Genuchten (VG), and Fredlund and Xing (FX) were used to obtain curve fitting parameters using the program "SWRC Fit" which performed nonlinear fitting of soil water retention curves. The SWRC Fit can simultaneously calculate the fitting parameters of these models with Root Mean Square Error values and draw the fitting curves. By comparing the results of the models using SWRC Fit, the model that best fits the laterite soil investigated will be chosen to be used for further analysis. The results show that the BC model represents the soil water retention curves better than the VG and FX models when the soil has distinct air entry suction. On the other hand, the VG and FX models can fit most soil water retention curves very well when discussion on the pore-size distribution is desired.

### 1. Introduction

Contaminants flow through compacted soil liners and covers are usually considered under saturated conditions during design stage. Nonetheless, the compacted soil barriers in reality are neither completely saturated nor completely dry, rather they are in an unsaturated state. Thus, unsaturated flow principles need to be properly simulated to determine the contaminant flow through compacted soil barriers in order to protect groundwater. Soil water characteristic curve (SWCC) which is the relationship between soil suction and water content is the main modeling parameter of unsaturated soil [1]. In recent years,



determination of the soil water characteristic curves (SWCCs) of soils has become an important tool in interpreting the engineering behaviour of unsaturated soils. Soil water characteristic curve, which defines a soil's ability to store and release water as it is subjected to various soil suctions, is an important tool to estimate and interpret unsaturated soil property functions [2-3]. The matric suction in unsaturated soil mechanics it is most notably defined as the difference between the pore air pressure and pore water pressure [4]. Such curve allows the prediction of the engineering behaviour of an unsaturated soil permeability, shear strength, volume change and deformability of unsaturated soils are mainly affected due to water content and suction [5].

Most sites for solid waste disposal are located in unsaturated materials zones because guidelines for siting and designing sanitary landfills have generally suggested or required that waste disposal take place above the water table [6]. Water movement above the water table usually occurs in the unsaturated state; soil water exists under tension by capillary forces at less than atmospheric pressures. Soil physicists, agricultural engineers, and others have extensively studied the physics of unsaturated flow. In recent years, the concept of unsaturated flow has become increasingly important to geoenvironmental engineers and hydrogeologists, especially regarding studies of the impact of waste disposal on groundwater [6].

In contrast to lining systems, covers are exposed to a much different environment where stresses are low, unsaturated conditions persists and interaction with the atmosphere occurs continuously [7]. Proper evaluation of the hydrology of compacted soil covers should be based on consideration of unsaturated flow and the unsaturated hydraulic conductivity of the soil since covers are unsaturated when compacted [8].

It is well recognized that the unsaturated soil properties are important in numerical analysis of geotechnical and geoenvironmental problems associated with unsaturated zone. The success of any numerical simulations greatly depends on the reliability of the input data such as the soil-water characteristic curve that defines the relationship between volumetric water content and matric suction [9].

For modeling and other numerical purposes, it is often convenient to provide the water retention characteristics in functional form, in which equation is selected amongst the numerous mathematical equations commonly used to describe the water retention characteristics [10]. Previous studies have proposed several simple procedures to predict the engineering behaviour of unsaturated soil using SWCC and saturated soil properties [11-16]. The procedures used to predict the engineering behaviour of unsaturated soils are simple and economical and therefore useful to practicing geotechnical and geoenvironmental engineers. SWCCs are useful for illustrating how compaction water content, index properties, and mineralogy affects the unsaturated hydraulic conductivity of any material in the barrier system of a waste containment facility and can be used in modeling flow and transport [17]. In this study, models suggested by Brooks and Corey (BC), van Genuchten (VG), and Fredlund and Xing (FX) were used to obtain curve fitting parameters using the program "SWRC Fit" that performs nonlinear fitting of soil water retention curves. This program automatically determines all the necessary conditions for the nonlinear fitting, such as the initial estimate of the parameters, and, therefore, users can simply input the soil water retention data to obtain the necessary parameters [12].

## **2. Material and Method**

### *2.1. Material*

A red laterite soil of granite origin was collected at a depth below 1m from a borrow pit using the method of disturbed sampling from Skudai campus (Johor) which is located at latitude 1°33'39"N and longitude 103°38'44"E of Universiti Teknologi Malaysia (UTM).

## 2.2. Method

Soil specimens were prepared at moulding water contents relative to optimum as follows: 2% dry of optimum water content; Optimum water content; and 2% wet of optimum water content.

The specimens were then compacted inside a mould using the British Standard light (BSL) compaction. They were subsequently extruded and a stainless-steel ring with a bevelled sharp cutting edge having inside diameter of 50 mm and height of 20 mm was used to core columns of soil from the specimens. These specimens were soaked to saturate before being subjected to pressure plate drying test. Measurements were made in triplicates for each sample and the average value is computed.

*2.2.1. Pressure Plate Test.* The procedure describes the determination of the SWCC using pressure plate apparatus (Figure 1). The pressure extractors are used to determine the water-holding characteristics of the soil sample. By analyzing the sample at different pressures, the characteristic pressure versus water content relationship is determined for that soil. The determination described here is based on desorption procedure that uses suction (1, 10, 30, 100, 300, 500, 800 to 1000 kPa). Procedures followed were in accordance with [18]. According to [5], soil water characteristic curves are usually measured for a suction range between 0 and 1000 kPa in the laboratory using conventional equipment. This suction range is of interest to geotechnical and geo-environmental engineers. During testing, six to eight data points are usually measured in order to determine the important features of the SWCC curve. The saturated soil specimens were placed in the pressure plate cell and pressure was applied to a predetermined value to induce matric suction. The test was terminated when the outflow stopped thus, indicating that specimens were in equilibrium with the applied matric suction. The specimens were removed from the cell and their volumetric water contents determined. The procedure was repeated to develop an entire soil water characteristic curve by subjecting the soil specimens to different pressures.

## 3. Discussion of Results

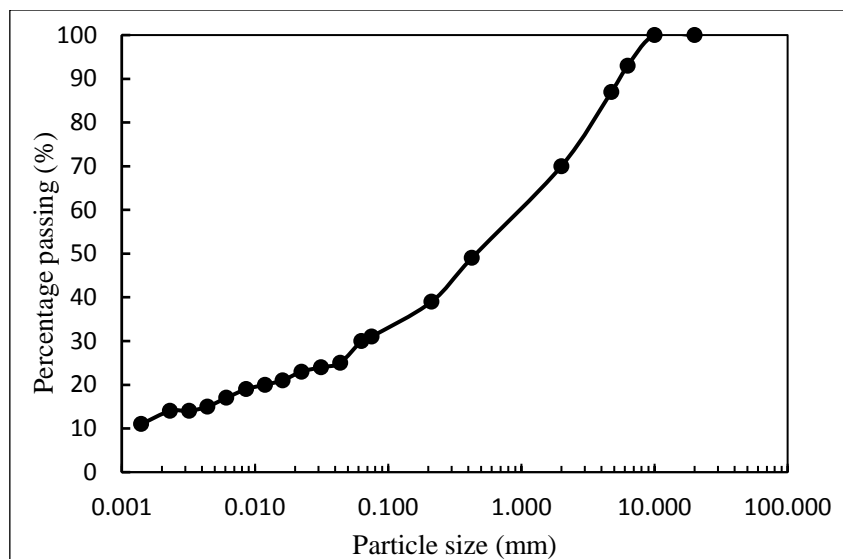
The results of the SWCC at different moisture content are presented.

### 3.1 Index Properties

Results of the laboratory tests carried out to determine the index properties and compaction characteristics of laterite soil are shown in Table 1. The particle size distribution curve of the laterite soil is shown in Figure 1. The Atterberg limits results revealed a liquid limit of 76.0 %, plastic limit of 42.0 %, and plasticity index of 34.0 %. Based on these data, the natural laterite soil is classified as very high plasticity sandy silt with gravel (MV) according to the British Standard (BS) classification [19].

**Table 1.** Index properties of laterite soil.

| Property                    | Value |
|-----------------------------|-------|
| Colour                      | Red   |
| Natural Moisture Content, % | 34    |
| Specific Gravity            | 2.7   |
| % Passing BS 63µm sieve     | 30    |
| OMC, %                      | 30    |
| MDD, Mg/m <sup>3</sup>      | 1.35  |
| Liquid Limit, %             | 76    |
| Plastic Limit, %            | 42    |
| Plasticity Index, %         | 34    |
| BS Classification           | MV    |

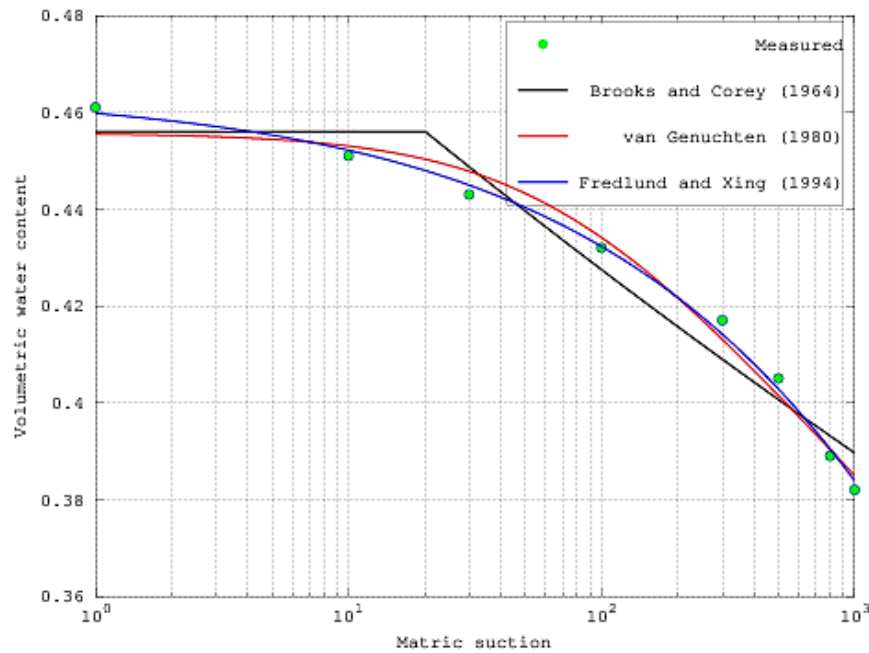


**Figure 1.** Particle size distribution curve.

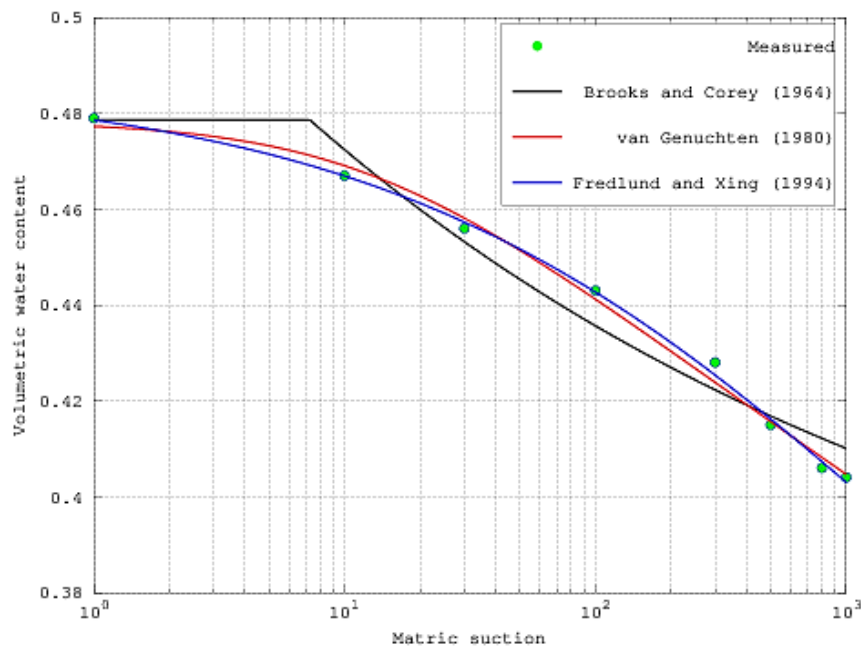
*3.2 Soil Water Characteristic Curves*

Soil water characteristic curve is an expression of the relationship between the matric suction and volumetric water content and they were developed for each compacted specimen using data from pressure plate test at various moisture contents. In this study, the effects of moulding water content for the laterite soil using models suggested by Brooks and Corey (BC), van Genuchten (VG), and Fredlund and Xing (FX) were employed to obtain curve fitting parameters using the program “SWRC Fit” which performed nonlinear fitting of soil water retention curves. The results are presented in Figures 2, 3 and 4 at dry, optimum and wet of optimum moisture contents, respectively based on different methods.

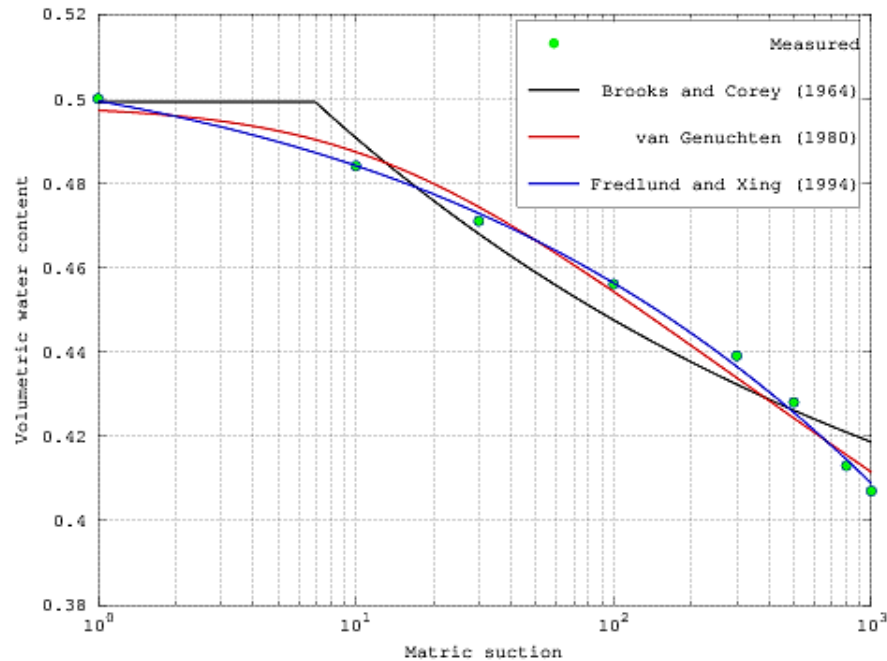
Generally, the measured and predicted SWCCs plotted at different moisture contents showed close agreement for all the models, but FX being the closest and thus preferable for the laterite soil used.



**Figure 2.** Variation of soil water characteristic for laterite soil at dry of optimum water content based on different methods.



**Figure 3.** Variation of soil water characteristic of laterite soil at optimum water content based on different methods.



**Figure 4.** Variation of soil water characteristic of laterite soil at wet of optimum water content based on different methods.

The variations of moisture content can be referred in [20] which clearly shown as specimen prepared on the dry side of optimum is lowest on the graph of the SWCC, while specimen prepared on the wet side of optimum is highest. Similarly, the suction is relatively lower on the dry of optimum specimen compared to optimum and wet of optimum specimen because water content affects the micro and macro fabric of the compacted soil [17]. According to [21], the micro structure is described as the elementary particle association within the soil, the macro structure is the arrangement of the soil aggregates. The samples prepared at dry of optimum has macro structural arrangement, with relatively larger pores located between soil particles within the clods of the laterite. Low suction values would be required to remove the water from these large pores. Therefore, the macro structure controls desaturation of compacted soil specimen prepared at water content dry of optimum [22-23]. Typically, samples compacted wet of optimum water content has micro structural arrangement. The pore spaces are not generally interconnected, and the increasing water content results in deflocculating the soil particle structure thus, reducing the voids. Therefore, the soil specimen tend to resist desaturation under an applied suction in comparison with to specimen compacted dry of optimum [22]. Samples compacted at optimum water content tends to fall between dry and wet of optimum since the boundary closed and open pores condition occurs at water content equal to the optimum [17, 22].

Moreover, the predicted SWCCs plotted were compared with the laboratory measured SWCC for the three models as shown in Figures 2-4. The general observation is that BC model tends to over predict the volumetric water content, while VG and FX tend to slightly under predict the volumetric water content. However, the overall measured and predicted SWCC showed close agreement between the measured and predicted values. Similar results were observed by [17, 22, 24].

A summary of the curve fitting parameters for Brooks and Corey, van Genuchten, and Fredlund and Xing at dry, optimum and wet of optimum moisture contents are presented in Table 2, 3 and 4 respectively. The parameter  $S_e$  is the effective saturation,  $\theta_s$  is the saturated water content and  $\theta_r$  is the residual water content,  $h$  is the suction,  $h_b$  is the air entry value and  $\lambda$  is the empirical parameter

representing the pore size distribution index,  $\alpha$  is related to the air entry value and the  $n$  parameter is related to pore size distribution of the soil that controls the slope of the SWCC, while  $m$  is related to a symmetry of the model curve. The results show that the BC model represents the soil water retention curves better than the VG and FX models when the soil has distinct air entry suction. On the other hand, the VG and FX models can fit most soil water retention curves very well when discussion on the pore-size distribution is desired [12].

**Table 2.** Curve fitting parameters at dry of optimum moisture content.

| Model             | Equation  | Parameters   |
|-------------------|---|--|
| Brooks and Corey  | $S_e = \begin{cases} \left(\frac{h}{h_b}\right)^{-\lambda} & (h > h_b) \\ 1 & (h \leq h_b) \end{cases}$ | $\theta_s = 0.45600$<br>$\theta_r = 1.3296e-07$<br>$h_b = 20.110$<br>$\lambda = 0.040282$            |
| van Genuchten     | $S_e = \left[ \frac{1}{1 + (\alpha h)^n} \right]^m \quad (m = 1 - 1/n)$                                 | $\theta_s = 0.45573$<br>$\theta_r = 5.8878e-06$<br>$\alpha = 0.011542$<br>$n = 1.0672$               |
| Fredlund and Xing | $S_e = \left[ \frac{1}{\ln [e + (h/a)^n]} \right]^m$  | $\theta_s = 0.46428$<br>$\theta_r = 2.3948e-06$<br>$a = 2.1824e+05$<br>$m = 5.5681$<br>$n = 0.43480$ |

**Table 3.** Curve fitting parameters at optimum moisture content.

| Model             | Equation  | Parameters  |
|-------------------|---|---|
| Brooks and Corey  | $S_e = \begin{cases} \left(\frac{h}{h_b}\right)^{-\lambda} & (h > h_b) \\ 1 & (h \leq h_b) \end{cases}$ | $\theta_s = 0.47867$<br>$\theta_r = 0.35137$<br>$h_b = 7.2497$<br>$\lambda = 0.15709$         |
| van Genuchten     | $S_e = \left[ \frac{1}{1 + (\alpha h)^n} \right]^m \quad (m = 1 - 1/n)$                                 | $\theta_s = 0.47836$<br>$\theta_r = 2.4575e-05$<br>$\alpha = 0.068863$<br>$n = 1.0394$        |
| Fredlund and Xing | $S_e = \left[ \frac{1}{\ln [e + (h/a)^n]} \right]^m$  | $\theta_s = 0.48710$<br>$\theta_r = 0.32825$<br>$a = 7147.4$<br>$m = 5.2266$<br>$n = 0.39924$ |



**Table 4.** Curve fitting parameters at wet of optimum moisture content.

| Model             | Equation  | Parameters   |
|-------------------|---|--|
| Brooks and Corey  | $S_e = \begin{cases} \left(\frac{h}{h_b}\right)^{-\lambda} & (h > h_b) \\ 1 & (h \leq h_b) \end{cases}$ | $\theta_s = 0.49916$<br>$\theta_r = 0.35987$<br>$h_b = 6.9679$<br>$\lambda = 0.17388$                |
| van Genuchten     | $S_e = \left[ \frac{1}{1 + (\alpha h)^n} \right]^m \quad (m = 1 - 1/n)$                                 | $\theta_s = 0.49845$<br>$\theta_r = 2.2604e-05$<br>$\alpha = 0.069880$<br>$n = 1.0450$               |
| Fredlund and Xing | $S_e = \left[ \frac{1}{\ln [e + (h/a)^n]} \right]^m$  | $\theta_s = 0.51639$<br>$\theta_r = 3.5247e-06$<br>$a = 3.3089e+05$<br>$m = 3.6390$<br>$n = 0.28958$ |

**4. Conclusions**

An investigation on a red laterite soil compacted at dry, optimum and wet of optimum moisture contents to determine its SWCC using various models was comprehended. Models by Brooks and Corey, van Genuchten, and Fredlund and Xing were used to obtain curve fitting parameters using the program “SWRC Fit” that performed nonlinear fitting of soil water retention curves. Samples prepared on the dry of optimum has low suction due to macro fabric which was required to remove the water from these large pores. Meanwhile, samples prepared on the wet side of optimum requires higher suction due micro fabric. Generally, BC model tends to slightly over predict the volumetric water content, while VG and FX tend to slightly varies the volumetric water content. In overall, measured and predicted SWCCs showed close agreement for all the models, but FX being the closest and thus preferable.

**5. References**

[1] M. A. Hezmi, R. Saari, M. Z. Zahari *et al.*, 2015 Soil Water Characteristic Curves Of Compacted Kaolin For Various Initial Moisture Content, *Jurnal Teknologi*, vol. **76**, no. 2, pp. 39-44.

[2] K. J. Osinubi, A. A. Amadi, 2010 Variations in Soil Water Characteristic Curves of Lateritic Soil Treated with Bentonite, in *GeoShanghai 2010 International Conference. Experimental and Applied Modeling of Unsaturated Soils*, pp. 88-95.

[3] X. Li, J. H. Li, L. M. Zhang, 2014 Predicting bimodal soil–water characteristic curves and permeability functions using physically based parameters, *Computers and geotechnics*, vol. **57**, pp. 85-96.

[4] K. R. Mahmood, A. H. A. Kareem, 2010 Nature of Soil-Water Characteristics Curves (SWCC) for Soils from Anbar Governorate, *Anbar Journal of Engineering Sciences (AJES)*, vol. **3**, no. 1, pp. 61.

[5] M. Azmi, S. A. M. Yusoff, M. H. Ramli *et al.*, 2016 Soil Water Characteristic Curves (SWCCs) of Mining Sand, *EJGE*, vol. **21** [2016], Bund. 22, pp 6987-6997.

[6] T. M. Johnson, K. Cartwright, R. M. Schuller, 1981 Monitoring of Leachate Migration in the Unsaturated Zone in the Vicinity of Sanitary Landfills, *Groundwater Monitoring & Remediation*, vol. **1**, no. 3, pp. 55-63.

- [7] C. H. Benson, 2001 Waste Containment: Strategies & Performance *Australian Geomechanics* vol. **36**, no. 4, pp. 1-25.
- [8] C. J. Miller, N. Yesiller, K. Yaldo *et al.*, 2003 Impact of Soil Type and Compaction Conditions on Soil Water Characteristic, *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 129, no. 12, pp. 1169-1170.
- [9] K.-K. Phoon, A. Santoso, S.-T. Quek, 2010 Probabilistic analysis of soil-water characteristic curves, *Journal of Geotechnical and Geoenvironmental Engineering*, vol. **136**, no. 3, pp. 445-455.
- [10] A. A. Amadi, K. J. Osinubi, 2016 Soil-Water Characteristic Curves for Compacted Lateritic Soil-Bentonite Mixtures Developed for Landfill Liner Applications, *Geo-Chicago 2016*, pp. 488-497.
- [11] A. Peters, W. Durner, 2008 A simple model for describing hydraulic conductivity in unsaturated porous media accounting for film and capillary flow, *Water Resources Research*, vol. **44**, no. 11.
- [12] K. Seki, 2007 SWRC fit—a nonlinear fitting program with a water retention curve for soils having unimodal and bimodal pore structure, *Hydrology and Earth System Sciences Discussions*, vol. **4**, no. 1, pp. 407-437.
- [13] K. i. Kosugi, 1996 Lognormal distribution model for unsaturated soil hydraulic properties, *Water Resources Research*, vol. **32**, no. 9, pp. 2697-2703.
- [14] D. Fredlund, A. Xing, S. Huang, 1994 Predicting the permeability function for unsaturated soils using the soil-water characteristic curve, *Canadian Geotechnical Journal*, vol. **31**, no. 4, pp. 533-546.
- [15] M. T. Van Genuchten, 1980 A closed-form equation for predicting the hydraulic conductivity of unsaturated soils, *Soil science society of America journal*, vol. **44**, no. 5, pp. 892-898.
- [16] R. Brooks, T. Corey, 1964 Hydraulic properties of porous media, *Hydrology Papers, Colorado State University*, vol. NO. 3, Fort Collins, Colorado.
- [17] J. M. Tinjum, C. H. Benson, L. R. 1997 Blotz, Soil-water characteristic curves for compacted clays, *Journal of geotechnical and geoenvironmental engineering*, vol. **123**, no. 11, pp. 1060-1069.
- [18] ASTM, D 3152-72 1994 Standard test method for capillary-moisture relationships for fine-textured soils by pressure-membrane apparatus., *ASTM, West Conshohocken, Pa.*
- [19] BSI, " Code of practice for site investigations (BS 5930). British Standards Institute, London," 1999.
- [20] Y. B. Yamusa, M. A. Hezmi, K. Ahmad *et al.*, 2018 Using Soil Water Characteristic Curve in Computing Unsaturated Hydraulic Conductivity of Compacted Tropical Soil, *ARPN Journal of Engineering and Applied Sciences*, vol. VOL. **13**, NO. 17, 4765-4770.
- [21] K. J. Mitchell, K. Soga, 2005 *Fundamentals of Soil Behavior: 3rd Edition*, John Wiley and Sons Inc., New Jersey.
- [22] O. A. Eberemu, 2008 "Evaluation of bagasse ash treated lateritic soil as a suitable material for waste landfill barrier (liner and cover)," civil engineering, Ahmadu Bello University, Zaria, Nigeria.
- [23] G. Moses, 2012 "Hydraulic and Contaminant Transport Performance of Compacted Bagasse Ash Treated Foundry Sand for Use in Waste Containment Facilities," Phd Thesis, Ahmadu Bello University, Zaria, Nigeria.
- [24] C. D. Shackelford, 1994 Waste-soil interactions that alter hydraulic conductivity, *Hydraulic conductivity and waste contaminant transport in soil: ASTM International*.

**Acknowledgement**

The authors gratefully acknowledged the financial supports given by the Universiti Teknologi Malaysia under the Research University Grant Scheme (RUG-Vot No. Q.J130000.2522.14H29 ) for financial support and contribution.