



Relationship between Shear Strength and Suction of Granitic Residual Soil

N.H. Abdullah*¹, Ahmad Rashidi N.R.², and Z. Mat Ariffin¹

¹ Dept. of Civil Engineering, School of Engineering and Computing, Manipal International University, Nilai, Negeri Sembilan.

² Dept. of Civil Engineering, Faculty of Engineering Built Environment and Information Technology, MAHSA University, Selangor.

KEYWORDS

Soil water characteristic curve
Slope stability
Granitic residual soil
Suction

ABSTRACT

Rainfall is very important elements in slope failure. Rainfall infiltrating into the slope is the main factor that triggers slope failure. The infiltration of the surface water affects both resisting and disturbing components of the slope which in turn decrease the slope stability factor. Shear strength parameters are very important for design slope and foundation. In this study, Consolidated Drained (CD) triaxial test were conducted on granitic residual soil specimens, both under saturated and unsaturated conditions with different moisture content at 16%, 17% and 18%. While, the Soil Water Characteristic Curve (SWCC) were developed using the pressure plate extractor apparatus and gives a result of residual suction, 148 kPa which equivalent to maximum apparent cohesion, 17 kPa. Therefore the shear strength variation with respect to suction was found to be non-linear for the entire test in accordance to the curved surface envelope soil shear strength model (CSESSM).

© 2022 The Authors. Published by Penteract Technology.

This is an open access article under the CC BY-NC 4.0 license (<https://creativecommons.org/licenses/by-nc/4.0/>).

1. INTRODUCTION

The formation of rocks is constantly subjected to weathering and erosion processes, which results in the formation of residual soils. The main difficulties of the residual soils are associated with the rainfall distribution and the effect of infiltration of the surface runoff on the earth. The slope failure cases on residual soil in the tropics are triggered by the infiltration of the surface runoff that occurs during heavy rainstorms. Rainfall is very important elements in slope failure [32] quoted that "rainfall-induced slope failure occur in response to climatic changes in many parts of the worlds. The infiltration changes the distribution of the matrix suction and in turn affects the apparent shear strength of the soil [14].

Shear strength envelope at failure was known to be plane envelope as introduced by Fredland, 1978. However there are many published data that shows that envelop is curved surface. Shear strength variation with suction is known with maximum value of c_{Smax} at residual suction. It shows that the shear strength respects to suction of granitic residual soil is also non-

linear. Thence, this study was primarily concerned with the study the variation shear strength with relate to suction of saturated and unsaturated specimen of granitic residual soil.

1.1 Granitic Residual Soil

Residual soil is a material formed in situ by weathering of rocks and remained at the place where it was formed. The amount and extent of weathering and the balance between physical, chemical and biological processes depends primarily on the climate and the material of the parent rock as well as local influenced such as drainage, topography and vegetation. However, granitic residual soils are generally sandy (high sand content) have a lower water content and lower liquid limit compared to basaltic or gabbroic soils. The mineralogy of granitic is quartz (30%), feldspar (60-65%) and biotite and hornblende [43]. Generally, in Malaysia, the type of residual granite soil is reddish in colour, which is from a laterite type of soil [12].

*Corresponding author:

E-mail address: N.H. Abdullah <nurul.huda@miu.edu.my >.

2785-8901/ © 2022 The Authors. Published by Penteract Technology.

This is an open access article under the CC BY-NC 4.0 license (<https://creativecommons.org/licenses/by-nc/4.0/>).

2. SOIL PROPERTIES

The soil samples taken from Putrajaya area were granitic residual soil Grade VI. Table 1 shows the basic properties of the soil sample. The residual soils obtained from site were reddish-brownish in colour which according to its particle size distribution the soil can be classified as very clayey gravelly SAND as shown in Figure 1.



Fig. 1. Location of Sample Area

Table 1. Basic Physical Properties of Soil Sample

Property Name	Putrajaya Granitic Residual Soil
Particle Size Distribution	
(i) Gravel (%)	19
(ii) Sand (%)	42.17
(iii) Silt (%)	15.18
(iv) Clay (%)	23.65
Moisture content (%)	24
Specific gravity, (Mg/m ³)	2.56
Liquid limit (%)	41
Plastic limit (%)	27.45
Plasticity index (%)	11

3. SOIL WATER CHARACTERISTIC CURVE (SWCC)

The SWCC for a soil is defined as the relationship between water content and suction for the soil [42]. This is an important relationship for the unsaturated soil mechanics. The water content can be gravimetric, volumetric or a degree of saturation. Also, the SWCC essentially shows the ability of an unsaturated soil to retain water under various matric suctions. It has a similar role as the consolidation curve, of a saturated soil, that relates void ratio or water content to effective stress. In addition, the SWCC of a soil dictates the manner by which the permeability, shear strength and a volume change of the soil will behave at different matric suctions upon drying and wetting [14].

In geotechnical engineering, Fredlund and Xing (1994) suggested the following SWCC equation:

$$\theta_w = \frac{\theta_s}{\left\{ \ln \left[e + \left(\frac{\varphi}{a} \right)^a \right] \right\}^m} \quad (1)$$

where

- θ_w = volumetric water
- θ_s = saturated volumetric water content
- φ = matric suction
- a, m are constant.

To obtain the SWCC's data, a common method that has been used was taken from the pressure plate extractor test [1] as shown in Figure 2. The SWCC of the soil samples were shown in Figure 3. The curve indicates that the residual suction of the test material is about 148 kPa according to the definition by [14]. Based on the graph SWCC, several steps had follow in process to determine residual suction. Furthermore, the graph SWCC was to identify maximum apparent cohesion. In the first step, tangent line from point suction 580 kPa to left of graph has been draw. Then, same procedure was repeating from 25 kPa which is draw a tangent line downward. Lastly, mark one intersection point from the tangent line. Hence, the point representing the moisture content at 17% and the residual suction at 148 kPa as is acceptable and justify.

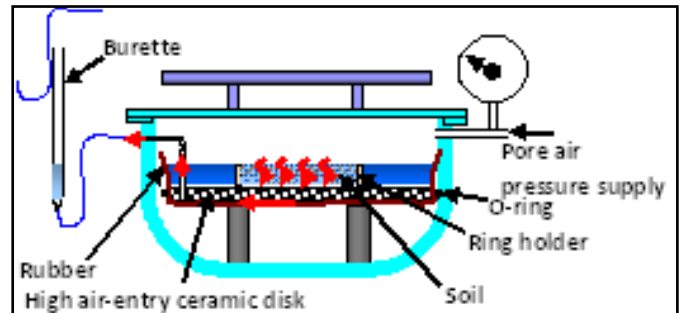


Fig. 2. Pressure Plate Extractor Apparatus Illustrating the Flow of Excess Water During the Equalization Process with the Specimen Initially Flooded with De-Aired Water

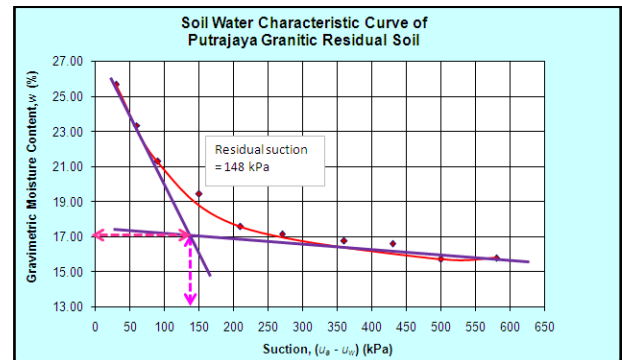


Fig. 3. Soil Water Characteristic Curve of Putrajaya Granitic Residual Soil

4. CURVED-SURFACE ENVELOPE SOIL SHEAR STRENGTH MODEL (CSESSM)

This model was developed to overcome limitation of the previous two models. The steep drop in shear strength near saturation is responsible for the steep drop in the stability factor when surface water infiltrates into the slope [26]. Whereas the actual behaviour of shear strength and suction is curved (not linear) and steep drop in both dimensions, when approaching minimum strength and suction equally becomes zero [26]. Perhaps, when applied in slope stability analysis, it is expected to make a better prediction on the risk of rain induced slope failures. Therefore, the shear strength parameter according to the non-linear type of envelope has to be determined especially for Malaysian Grade IV type of soil. This new slope stability equation applies the latest and most accurate soil shear strength model in order to produce a good estimate on the resisting components. This model encompasses shear strength behaviour under both saturated and unsaturated conditions. It will give a result of shear strength prediction with respect to the change in effective stress and suction [26]. There are seven shear strength parameters to choose are shown in Figure 4.

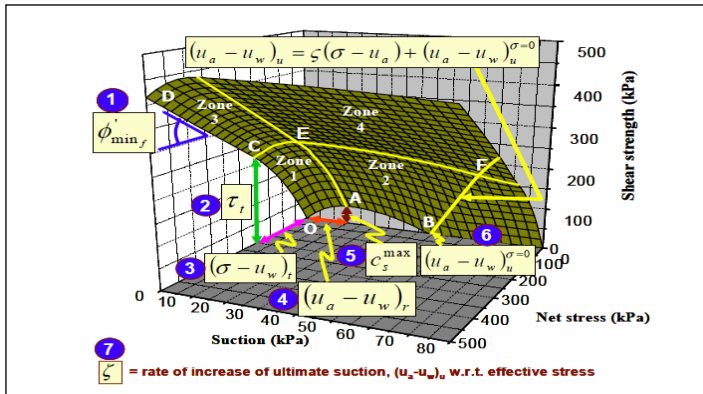


Fig. 4. Curved-surface Envelope Shear Strength Model (Md. Noor and Anderson, 2006)

A series of CD triaxial tests were performed on fully saturated and unsaturated samples. The amounts of moisture content were 16%, 17% and 18% of the each sample. This test was carried out by size of specimen with 50 mm x 100 mm. The results obtained from the triaxial tests were used to analyze the shear strength behaviours due to the shear strength parameters according to the CSESSM of [26]. The shear strength parameters according to the model are as follows;

- i. Transition effective stress, $(\sigma - u_w)_t$
- ii. Transition shear-strength, τ_t
- iii. Minimum friction angle at failure, $(\phi'_{min})_f$
- iv. Apparent cohesion, c_s^{max}

$$\tau = (\sigma - u_a) \tan \phi'_{min_f} + \left[\tau_t - (\sigma - u_w)_t \tan \phi'_{min_f} \right] + \frac{(u_a - u_w)}{(u_a - u_w)_r} \left[1 + \frac{(u_a - u_w)_r - (u_a - u_w)}{(u_a - u_w)_r} \right] c_s^{max} \quad (2)$$

Besides, combination the Mohr circles and the Mohr-Coulomb envelope on saturated and unsaturated specimens are plotted in Figure 5.

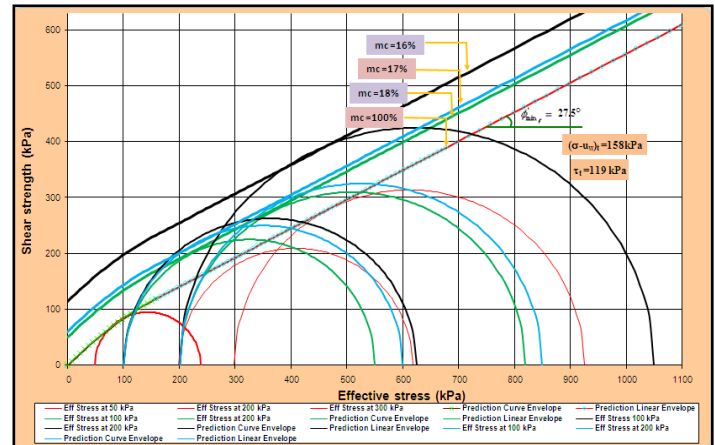


Fig. 5. Curvilinear Shear Strength Envelope of Saturated and Unsaturated Specimens of Putrajaya

5. SUCTION WITH RESPECT TO SHEAR STRENGTH

The effect of wetness on shear strength is characterized based on a stress state variable known as suction. The suction effect is derived from the surface tension force on the water meniscus, which clings between soil particles [18] and generally its magnitude increases as moisture decreases. However, shear strength does not indefinitely increase with suction since it started to decrease beyond residual suction [10]; [16]; [40]; [26].

Referring to Equation 2, the graph shear strength versus suction was established shown in Figure 6. Putrajaya granitic residual soil has the value of moisture content at 17% is maximum apparent cohesion and the shear strength envelope of this soil specimen on saturated and unsaturated cohesion is curvilinear i.e. in accordance to the curved surface envelope soil shear-strength model (CSESSM) of Md. Noor and Anderson (2006).

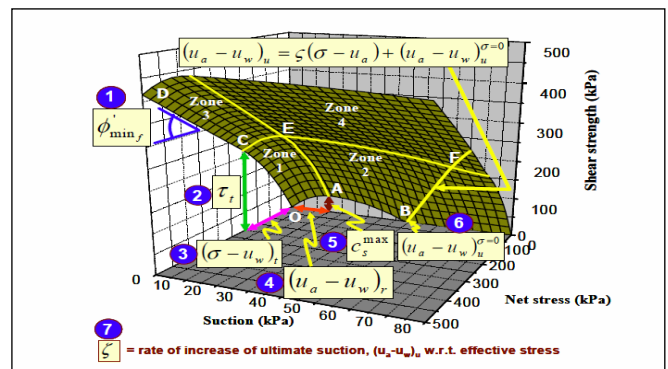


Fig. 6. Shear Strength Respect to Suction of Putrajaya Granitic Residual Soil

Therefore, the application of this curve surface envelope shear strength model, which represents realistic soil shear strength behaviour especially at low stress levels, was very important since in shallow slope failure, most of the time, was confined within 2 to 3 metres from the surface [6]. The stress

level within this depth range must be less than 80 kPa which is essentially low.

6. CONCLUSION

Based on result and observation obtained, the conclusions that can be drawn are:

- i. The graph shear strength versus suction is non-linear whereby the saturated condition is zero cohesion and maximum apparent cohesion is a peak of non-linear.
- ii. Pressure plate extractor test is suitable to determine SWCC of Putrajaya granitic residual soil and gives a result of residual suction, 148 kPa which is equivalent to c_{smax} , 17 kPa.
- iii. Putrajaya granitic residual soil has the value of moisture content at 17% is the maximum apparent cohesion and the shear strength envelope of this soil specimen on saturated and unsaturated cohesion is non-linear.
- iv. Soil suction does play role towards increasing the shear strength of saturated and an unsaturated soil.

REFERENCES

- [1] Agus, S.S., Leong, E.C. and Rahardjo, H., "Soil Water Characteristic Curves of Singapore Residual Soils." *Geotechnical and Geological Engineering* 19, 2001, pp 285-309.
- [2] Alonso, E.E., and Josa, A., "A Constitutive Model for Partially Saturated Soils." *Geotechnique*, 40, 1990, pp 405-430.
- [3] Blight, G.E. and Simmons, "Profile Description and Sampling Methods." *Mechanics of Residual Soil*. Rotterdam, Netherlands, 1997, pp 47-50.
- [4] Blight, G.E., "Origin and Formation of Residual Soils." *Mechanics of Residual Soils*. Balkema, Rotterdam, 1997.
- [5] Brand, E.W., Premchitt, J. and Phillipson, H.B., "Relationship Between Rainfall and Landslides in Hong Kong." *Proceedings of the 4th International Symp. Landslides*, Toronto, (1), 1984, pp 377-384.
- [6] Brand, E.W., "Landslides: Extent and Economic Significance." *Proceedings of the 28th International Geological Congress: Symposium on landslides*, Washington D.C., 1989, 303-322.
- [7] Bujang B.K. Huat, Gue See Sew and Ali, F.H. (). "Tropical Residual Soils Engineering." London: A.A. Balkema, 2004, pp 57-71.
- [8] Das, B.M., "Principles of Geotechnical Engineering." 1998, pp 68-69.
- [9] Escario, V., and Saez, J., "The Shear Strength of Partly Saturated Soils." *Geotechnique*, 36(3), 1986, pp 453-456.
- [10] Escario, V., and Juca, J., "Strength and Deformation of Partly Saturated Soils." *Proceedings of the 12th International Conference on Soil Mechanics and Foundation Engineering*, Rio de Janeiro: 3, 1989, pp 43-46.
- [11] Fookes, P.G., Dearman, W.R. and Franklin, J.A., "Some Engineering Aspects of Rock Weathering." *Quarterly Journal of Engineering Geology* 4, 1971, pp 139-185.
- [12] Fookes, P.G., "An Introduction to Weathered Rock and Residual Soils for Engineers." *Warta Geologi*, Vol. 12, No. 1-6, 1986, pp 60-71.
- [13] Fookes, P.G., "Tropical Residual Soils." 1st edition London: The Geological Society London, 1997.
- [14] Fredlund, D.G. and Rahardjo, H., "Soil Mechanics for Unsaturated Soils." John Wiley and Sons, Canada, 1993.
- [15] Fredlund, D.G. and Xing, A., "Equation for the Soil Water Characteristic Curve." *Canadian Geotechnical Journal* 31, 1994, pp 521-532.
- [16] Gan, J.K.M., and Fredlund, D.G., "Shear Strength Characteristics of Two Saprolitic Soils." *Canadian Geotechnical Journal*, 33, 1996, pp 595-609.
- [17] Ismail A., "Comparison Study of Slope Analysis Using Limit Equilibrium Method and Finite Element Method at Seksyen 92.5, FT 175, Jalan Pedu, Mong gajah, Kedah Darul Aman." Master Thesis, UiTM Malaysia Shah Alam., 2008
- [18] Kaye, G.W.C. and Laby, T.H., "Tables of chemical constants." Longman 14th Edition., 1973.
- [19] Kepli, M.I., "Properties of Granite Derived Residual Soils." Final Year Project, Mara Institute of Technology, 1994.
- [20] Khairul, N.M.Y., "Mineralogi, Mikrostruktur dan Komposisi Kimia Tanah Baki Granit di Semenanjung Malaysia." Master Thesis, Universiti Teknologi Malaysia, 2002.
- [21] Komoo, I. and Mogana, S.N., "Physical Characterization of Weathering Profile of Clastic Metasediments in Peninsular Malaysia." *Proceeding of the 2nd International Conference on Geomechanics in Tropical Soils*, Singapore. 1, 1988, pp 37-42.
- [22] Leong, E.C. and Rahardjo, H. (). "Review of Soil Water Characteristic Curve Equations." *Journal of Geotechnical and Geoenvironmental Engineering* 123(12), 1997, pp 1106-1117.
- [23] Little, A.L., "The Engineering Classification of Residual Tropical Soils." *Proceedings of the 7th International Conference on Soil Mechanics and Foundation Engineering*. Mexico City, 1, 1969, pp 1-10.
- [24] MacCarthy, D.F., "Essentials of Soil Mechanics: Basic Geotechnics." Englewood Cliffs, New Jersey: Regents/ Prentice Hall, 1993.
- [25] McLean and Gribble, C.D., "Geology for Civil Engineers." London: E and FN Spon, 1979.
- [26] Md. Noor, M.J. and Anderson, W.F., "A Comprehensive Shear Strength Model for Unsaturated Soils." *Proceeding of the 4th International Conference on Unsaturated Soils*, Arizona, U.S.A, Vol.(2), 2006, pp 1992-2003.
- [27] Melinda, F., Rahardjo, H., Han, K.K. and Leong E.C., "Shear Strength of Compacted Soil under Infiltration Condition." *Journal of Geotechnical and Geoenvironmental Engineering*, 2004, pp 807-817.
- [28] Mirjat, M.S., Rodgers, M., Mulqueen, J., and Gibbons, P., "Measured and Modelled Soil Water Characteristic Curves for a Sandy Loam Soil." *Malaysian Journal of Soil Science* Vol. 9, 2005, pp 15-27.
- [29] Mohamed, T.A., Ali, F., Hashim, S. and Bujang B.K. Huat., "Relationship between Shear Strength and Soil Water Characteristic Curve of an Unsaturated Granitic Residual Soil." *American Journal Environment Science*, Volume 2, Issue 4, 2006, pp 126.
- [30] Public Work Institute, Malaysia (IKRAM), "Tropical Weathered In Situ Material." *GEO GUIDES*, 1996, pp 1-5.
- [31] Rahardjo, H. and Fredlund, D.G., "Calculation Procedures for Slope Stability Analyses Involving Negative Pore-Water Pressures." *Proceeding International Conference Slope Stability Engineering, Development, Applications*, Isle of Wight, U.K, 1991.
- [32] Rahardjo, H., Aung, K.K., Leong, E.C. and Rezaur, R.B., "Characteristics of Residual Soils in Singapore as Formed by Weathering." *Volume 73, Issue 1-2*, 2004, pp 157-169.
- [33] Rahardjo, H., Satyanaga, A. and Leong, E.C., "Slope of Real Time-Monitoring in Slope Stability." *International Seminar on Civil and Infrastructure Engineering*, Proceeding, Keynote Paper, Faculty of Civil Engineering, UiTM Malaysia, 2008.
- [34] Roslan, Z., "Relationship between Soil Grading Characteristics and Soil Erosion Risk." 6th Regional Conference in Geotechnical Engineering (GEOTROPIKA 2001). *Fakulti Kejuruteraan Awam, Universiti Teknologi Malaysia*, 05 - 07 November, 2001, Kuching, Malaysia, 2001, pp 107-116.
- [35] Samad A.R., "Investigation of Slope Failure at Precint 9, Putrajaya on 22nd, 2008.
- [36] Master Thesis, Faculty of Civil Engineering, Universiti Teknologi MARA, Malaysia, March 2007.
- [37] Taha, M.R., Sarac., D., Chik, Z. and Nayan, K.A.M., "Geotechnical and Geoenvironmental Aspects of Residual Soils." *Proceeding of 4th Regional Conference in Geotechnical Engineering (GEOTROPIKA 97)*, Johor, Malaysia, 1997, pp 331-341.
- [38] Tan, B.K., "Engineering Geology of Tropical Residuals Soils in Malaysia, Tropical Residual Soils Engineering." *Chapter 14-Country Case Study* Balkema, Rotterdam, 2004, pp 237-244.
- [39] Thamer, A.M., Faisal, H.A., Hashim, S. and Bujang B.K. Huat, "Relationship between Shear-strength and Soil Water Characteristic Curve of an Unsaturated Granitic Residual Soil." *American Journal of Environmental Sciences* 2 (4), 2006, pp 42-145.

- [40] Toll, D.G., Ong, B.H., and Raharjo, H., "Triaxial Testing of Unsaturated Samples of Undisturbed Residual Soil from Singapore." Proceedings of the Conference on Unsaturated Soils for Asia, Singapore, Balkeema, 2000, pp 581-586.
- [41] Vanapalli, S., Fredlund, D.G., Pufahl, D.E. and Clifton, A.W., "Model for the Prediction of Shear Strength with Respect to Soil Suction." Canadian Geotechnical Journal 33, 1996, pp 379-392.
- [42] Williams, P.J., "The Surface of the Earth in an Introduction to Geotechnical Science." Longman Inc., New York, 1982.
- [43] Zhao, J., "Engineering Properties of the Weathered Bukit Timah Granite and Residual Soils." Regional Conference in Geotechnical Engineering 94. Melaka, Malaysia, 1994.