

**SLOPE STABILIZATION INFLUENCED
BY UNSATURATED SOIL**

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SUPERVISOR'S DECLARATION

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Engineering Technology
UNIVERSITI MALAYSIA PAHANG

MAY 2018

ACKNOWLEDGEMENTS

First and foremost, I am grateful to Almighty ALLAH for giving me the courage and insight to complete this thesis exactly in time given.

I am grateful and would like to express my gratitude to my supervisor Dr. Mohd Fakhrurrazi bin Ishak for his ideas, guidance and continuous encouragement in completing this research.

I want to express my gratitude to my parents, Zolkepli bin Haji Hasan and Norainiyah binti Nong Teh for their support and encouragement in this study. Thank you also to my brother.

Next, I would also like to thank all staffs in Faculty of Engineering Technology especially Mr. Shahrul, Mr. Azahar, Mr Jasrul, Mr Badwi, Mr Zul, Miss Yani and all that helps me a lot in many ways that make my stay at UMP pleasant and unforgettable.

In addition, I would like to express my thanks to all of my friends for their support and guidance in completing this thesis. Thanks to UMP, Ministry of Higher Education and also Yayasan Pahang for their sponsorship throughout my study.

Lastly, I would like to express my gratitude to all that is directly or indirectly involved in this study as without their help, this study would never be completed. Only Allah can repay their deeds and reserve them a special place in the heaven.

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LIST OF SYMBOLS

c'	Effective cohesion
e	Void ratio
g	Gravity = 9.81 m/s ²
G_s	Specific gravity
n	Porosity
μ_a	Pore-air pressure
μ_w	Pore-water pressure
$(\mu_a - \mu_w)$	Matric suction
χ	Parameter related to the soil degree of saturation
ϕ'	Effective friction angle
ϕ^b	Angle indicating unsaturated
π	Osmotic suction
ρ_b	Bulk density
ρ_d	Dry density
σ	Total normal stress
σ'	Effective normal stress
τ_f	Shear stress at failure

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ABSTRAK

Kajian ini merangkumi kaedah-kaedah yang digunakan untuk kestabilan cerun melibatkan tanah yang tidak tepu. Dua kaedah iaitu kaedah mudah Bishop dan kaedah Fellenius digunakan untuk menentukan faktor keselamatan (FOS) cerun tanah tidak tepu. Oleh kerana kedua-dua kaedah tersebut hanya boleh digunakan untuk menentukan kestabilan cerun melibatkan tanah tepu, pengubahsuaian terhadap formula perlu dilakukan. Formula asal kaedah mudah Bishop perlu diubahsuaikan dengan menambah elemen sedutan matrik, $(\mu_a - \mu_w)$ dan juga sudut geseran tidak tepu, ϕ^b supaya kaedah ini dapat diguna pakai untuk mengira kestabilan cerun melibatkan tanah tidak tepu. Kaedah Fellenius telah diubahsuaikan oleh penyelidik terdahulu. Kajian ini melibatkan beberapa pendekatan seperti pengumpulan sampel, kajian makmal, dan juga analisa cerun. Sampel tanah diambil dari Kolej Matrikulasi Pahang melibatkan sampel terganggu dan tidak terganggu. Kajian makmal dilakukan untuk menentukan ciri index dan juga ciri kejuruteraan tanah. Hasil analisis menunjukkan tanah di kawasan Matrikulasi Pahang boleh dikategorikan sebagai tanah lumpur berpasir dengan kadar keplastikan yang tinggi. Hasil keputusan ujikaji ciri kejuruteraan memberi nilai perpaduan sebanyak 9kPa, sudut geseran tepu, ϕ' sebanyak 25°, manakala sudut geseran tidak tepu, ϕ^b sebanyak 21°. Analisa cerun untuk mereka bentuk ukuran cerun dilakukan dengan menggunakan SLOPE/W. Pengiraan faktor keselamatan (FOS) dilakukan menggunakan kaedah mudah Bishop dan kaedah Fellenius. Untuk permulaan, faktor keselamatan ditentukan menggunakan SLOPE/W, setelah itu menggunakan pengiraan biasa untuk memastikan hanya perbezaan yang kecil terhadap faktor keselamatan (FOS) apabila pengiraan menggunakan perisian dan juga pengiraan biasa. Akhir sekali, faktor keselamatan (FOS) untuk cerun tanah tidak tepu yang ditentukan menggunakan kedua-dua kaedah akan dibandingkan untuk menentukan kaedah yang memberi faktor keselamatan yang lebih tinggi ketika ada ataupun tiada sedutan. Dari hasil keputusan analisa cerun, secara kesimpulannya, faktor keselamatan akan lebih tinggi untuk kedua-dua cerun dengan jenis tanah tepu dan tidak tepu jika dikira menggunakan kaedah mudah Bishop jika dibandingkan dengan kaedah Fellenius.

ABSTRACT

This study provides the exploration of methods for slope stabilization influenced by unsaturated soil. Two methods known as Bishop's Simplified method and also Fellenius's method are used in order to determine the factor of safety (FOS) of unsaturated soil slope. Since these methods were only applicable to determine the FOS value of saturated soil slope only, some modifications need to be done. The original formula of Bishop's Simplified method will be modified by adding the elements of matric suction, $(\mu_a - \mu_w)$ and unsaturated friction angle ϕ^b so that it is applicable to calculate slope stability of unsaturated soil slope. Fellenius's method was already modified by previous researcher. The research employed several approaches i.e sample collection, laboratory experimental and slope analysis. The soil sample was collected at Pahang Matriculation College involving disturbed and undisturbed samples. The laboratory works were conducted to determine both index properties and engineering properties of soil. From the analysis, the soil at Pahang Matriculation College can be considered as Sandy SILT with high plasticity. From the result of engineering properties, the cohesion value is 9 kPa, the saturated friction angle ϕ' is 25° and the unsaturated friction angle ϕ^b 21°. The slope analysis to design the slope measurement was conducted using SLOPE/W. The FOS calculation involved both Bishop's and Fellenius's methods. The FOS values were determined from SLOPE/W first, and then using manual calculation to make sure there was only little percentage of difference of FOS value when calculating using both software and manual calculation. Finally, the FOS values for unsaturated soil slope for both methods were compared to determine which method gave higher FOS value with and without suction. From the result of analysis, it can be concluded that, the FOS value for both saturated and unsaturated soil slope is much higher when calculated using Bishop's Simplified method compare to Fellenius's method.

REFERENCES

- Adefemi, B.A. and Wole, A.C. (2013). Soil-Water Characteristic Curves for Compacted Abandoned Dumpsite Soil. *Electronic Journal of Geotechnical Engineering*. 18. 3315-3338.
- Agus, S.S., Leong, E.C. and Rahardjo, H. (2005). Estimating Permeability Functions of Singapore Residual Soils. *Engineering Geology*. 78. 119-133.
- Ahmad, F., A., Yahaya, A.S. and Farooqi, M.A. (2006). Characterization and Geotechnical Properties of Penang Residual Soils with Emphasis on Landslides. *American Journal of Environmental Sciences*, 2(4): 121-128.
- Aitchison, G.D. (1961). Relationship of Moisture Stress and Effective Stress Functions in Unsaturated Soils. *Pore Pressure and Suction in Soils Conference*. London, England: 47-52.
- Ali, N. (2007). *The Influence of Vegetation Induced Moisture Transfer on Unsaturated Soils*. Doctor Philosophy. University of Cardiff, United Kingdom.
- Ali, N., Farshchi, I., Mu'azu, M.A. and Rees, S.W. (2012). Soil-Root Interaction and Effects on Slope Stability Analysis. *Electronic Journal of Geotechnical Engineering*, 17, 319-328.
- Aryal, K.P. (2006). *Slope Stability Evaluations by Limit Equilibrium and Finite Element Methods*. Doctor Philosophy. Norwegian University of Science and Technology.
- Azmi, M., Yusoff, S.A.M., Ramli, M.H. and Hezmi, M.A. (2016). Soil Water Characteristic Curves (SWCCs) of Mining Sand. *Electronic Journal of Geotechnical Engineering*. 21. 6987-6997.
- Baba, K., Bahi, L., Ouadif, L. and Akhssas, A. (2012). Slope Stability Evaluations by Limit Equilibrium and Finite Element Methods Applied to a Railway in the Moroccan Rif. *Open Journal of Civil Engineering*. 2. 27-32.
- Bacic, B. and Uljarevic, M. (2014). Slope Stability Analysis. *International Conference Contemporary Achievements in Civil Engineering, Subotica, Serbia*. 379-384.
- Bishop, A.W. (1955). The Use of the Slip Circle in the Stability Analysis of Earth Slopes. *Geotechnique*, 5 (1), 7-17.
- Bland, W. and Rolls, D. (1998). *Weathering*. London: Arnold.
- Blight, G.E. (2012). Origin and Formation of Residual Soils. *Mechanics of Residual Soils*. London, UK, Taylor & Francis Group plc.
- Brand, G.E. and Philipson, H.B. (1985). Sampling and Testing of Residual Soils – A Review of International Practices. *Technical Committee on Sampling and Testing of Residual Soils, International Society for Soil Mechanics and Foundation Engineering*: 7-22.
- BSI, (1999). *Code of Practice for Site Investigations, (BS 5930)*. London: British Standard Institution.

- BS, (1990). *Methods of Tests for Soils for Civil Engineering Purposes, (BS 1377: Part 1-9)*. London: British Standard Institution.
- Cai, F. and Ugai, K. (2004). Numerical Analysis of Rainfall Effects on Slope Stability. *International Journal of Geomechanics, ASCE, 4(2)*: 69-78.
- Charlafti, M. (2014). Slope Stability and Vegetation. *Journal of Architectural Engineering Technology, 3(4)*. 1-8.
- Chowdhury, R., Flentje, P. and Bhattacharya, G. (2010). *Geotechnical Slope Analysis. CRC Press, Taylor & Francis Group, London, Uk.*
- Cui, P., Chen, X.Q., Zhu, Y.Y., Su, F.H., Wei, F.Q., Han, Y.S., Liu, H.J. and Zhuang, J.Q. (2011). The Wenchuan Earthquake (May 12, 2008), *Sichuan Province, China, and Resulting Geohazards, Nat. Hazards, 56 (1)*, 19-36.
- da Costa Teixeira, E.K., de Azevedo, R.F., Ribeiro, A.G.C., de Azevedo, I.C.d.A.D. and Candido, E.S. (2015). Influence of Rainfall Infiltration on the Stability of a Residual Soil Slope. *Electronic Journal of Geotechnical Engineering, 20*. 13321-13336.
- Duncan, J.M. (1996). State of the Art: Limit Equilibrium and Finite Element Analysis of Slopes. *J., Geotech. Engg., 122*, 577-596.
- Duraisamy, Y. (2010). Engineering Properties and Collapsibility Rate of Gambang Residual Soil. *International Journal of civil Engineering and Geoenvironmental, 11-18*.
- Egeli, I. and Pulat, F.H. (2011). Mechanism and Modelling of Shallow Soil Slope Stability During High Intensity and Short Duration Rainfall. *Scientia Iranica, Transaction A: Civil Engineering, 18*: 1179-1187.
- Esposito, E., Porfido, S., Simonelli, A.L., Mastrolorenzo, G. and Iaccarino, G. (2000). Landslides and Other Surface Effects Induced by the 1997 Umbria-Marche Seismic Sequence. *Eng., Geol., 58 (3)*, 353-376.
- Fellenius, W. (1936). Calculation of the Stability of Earth Dams. *Trans. 2nd Int. Cong. Large Dams, Washington*, 445-459.
- Feng, L., Wang, G., Zhang, M. and Xie, W. (2015). A Case Study: Characteristics of Unsaturated Loess (Q₃) Sampling on Loess Plateau, NW China. *10th Asian Regional Conference of IAEG, 1-4*.
- Fourie, A. B., Irfan, T.Y., Queiroz de Carvalho, J.B., Simmons, J.V. and Wesley, L.D. (2012). Microstructure, Mineralogy and Classification of Residual Soils. *Taylor & Francis Group plc, London, UK.*
- Fredlund, D.G. and Krahn, J. (1977). Comparison of Slope Stability Methods of Analysis. *Canadian Geotechnical Conference, Vancouver, B.C., 14*, 429-439.
- Fredlund, D.G. and Morgenstern, N. R. (1977). Stress State Variable for Unsaturated Soils. *Journal for Geotechnical Engineering Division, ASCE, 103, GT5*, 447-466.

- Fredlund, D.G. and Rahardjo, H. (1993). Soil Mechanics for Unsaturated Soils. *Canada: John Wiley & Sons, Inc, Printed Ltd.*
- Fredlund, D.G. and Xing, A. (1994). Equation for the Soil-Water Characteristic Curve. *Canadian Geotechnical Journal*. 31: 521-532.
- Fredlund, D.G., Krahn, J. and Pufahl, D.E. (1981). The Relationship between Limit Equilibrium Slope Stability Methods. *Proceedings of the International Conference of Soil Mechanics and Foundation Engineering*, 3, 409-416.
- Fredlund, D.G., Morgenstern, N.R. and Widger, R.A. (1978). The Shear Strength of Unsaturated Soil. *Canadian Geotechnical Journal*, 15: 313-321
- Fredlund, D.G., Ng, C.W.W., Rahardjo, H. and Leong, E.C. (2001). Unsaturated Soil Mechanics: Who Needs It? *Geotechnical News, December. GeoSpec., Bi-Tech Publishing, Vancouver, B.C., Canada*: 43-45.
- Fredlund, D.G., Rahardjo, H. and Gan, J.K-M. (1987). Non-Linearity of Strength Envelope for Unsaturated Soils. *Proceeding, 6th International Conference On Expensive Soils*, New Delhi, India, 49-54.
- Fredlund, D.G., Xing, A., Fredlund, M.D. and Barbour, S.L. (1996). The Relationship of the Unsaturated Shear Strength to the Soil-Water Characteristic Curve. *Canadian Geotechnical Journal*, 33(3): 440-448.
- Fredlund, D.G., Xing, A. and Huang, S. (1994). Predicting the Permeability Function for Unsaturated Soils Using the Soil-Water Character Curve. *Canadian Geotechnical Journal*, 31(3): 533-546.
- Futai, M.M., Almeida, M.S.S. and Lacerda, W.A. (2004). Yield Strength, and Critical State Behavior of a Tropical Saturated Soil. *Geotechnique*. 130(11): 1169-1179.
- GEO-SLOPE (2012). Stability Modelling with SLOPE/W. *An Engineering Methodology. GEO-SLOPE International Ltd. Calgary, Alberta, Canada T2P 2Y5.*
- Gledinning, S., Loveridge, F., Starr-Keddle, R.E., Bransby, M.F. and Hughes P.N. (2009). Role of Vegetation in Sustainability of Infrastructure Slopes. *Geotech. Eng., Proc. Inst. Civil Eng.*, 162, 101-110.
- Goh, S.G., Rahardjo, H. and Leong, E.C. (2010). Shear Strength Equations for Unsaturated Soil Under Drying and Wetting. *Journal of Geotechnical and Geoenvironmental Engineering*. April, 136(4), 594-606.
- Goh, S.G., Rahardjo, H. and Leong, E.C. (2015). Modification of Triaxial Apparatus for Permeability Measurement of Unsaturated Soils. *Soils and Foundations*. 55. 63-73.
- Gopal, P. and Kumar, T.K. (2014). Slope Stability and Seepage Analysis of Erath Dam of a Summer Storage Tank: A Case Study by Using Different Approaches. *International Journal of Innovative Research in Advance Engineering (IJIRAE)*. 1(12). 130-134.

- Handoko, L., Yasufuku, N., Oomine, K. and Hazarika, H. (2013). Suction Controlled Triaxial Apparatus for Saturated-Unsaturated Soil Test. *International Journal of GEOMATE*. 4(1). 466-470.
- Ho, I. (2014). Parametric Studies of Slope Stability Analyses Using Three-Dimensional Finite Element Technique: Geometric Effect. *Journal of GeoEngineering*. 9(1). 33-43.
- Hossain, M.A. and Islam, A. (2016). Numerical Analysis of the Effects of Soil Nail on Slope Stability. *International Journal of Computer Applications*. 141(8). 12-15.
- Huat, B.K., Ali, F. and Abdullah, A. (2005). Shear Strength Parameters of Unsaturated Tropical Residual Soils of Various Weathering Grades. *Electronic Journal of Geotechnical Engineering*. 0564:1-13.
- IAEG (1981). Rock and Soil Description for Engineering Geological Mapping, *International Association of Engineering Geology Bulletin*, 24: 235-274.
- Ibrahim, K.M.H.I. (2014). Effect of Percentage of Low Plastic Fines on the Unsaturated Shear Strength of Compacted Gravel Soil. *Ain Shams Engineering Journal*. 6. 413-419.
- Ige, O.O., Oyeleke, T.A., Baiyegunhi, C., Oloniniyi, T.L. and Sigabi, L. (2016). Liquefaction, Landslide and Slope Stability of Soil from Part of Kwara, Kogi, and Anambra States of Nigeria. *Journal of Natural Hazard and Earth System Sciences*. 1-39.
- Ishak, M.F., Ali, N. and Kassim, A. (2012). Tree Induce Suction for Slope Sustainability. *Journal of Applied Mechanics and Materials*. Vol. 170-173. 1334-1338.
- Ishak, M.F., Ali, N. and Kassim, A. (2013). The Effect of Tree Induce Suction on Slope Stabilization Analysis. *International Journal of Civil Engineering and Geo-Environmental*. 4, 15-22.
- Ishak, M.F., Ali, N. and Kassim, A. (2013). The Influence of Tree Induced Suction on Soil Suction Profiles. *International Journal of Research in Engineering and Technology*. 2(9). 187-193.
- Ishak, M.F. (2014). *Tree Water Uptake on Suction Distribution in Unsaturated Tropical Residual Soil Slope*. Doctor Philosophy. Universiti Teknologi Malaysia, Skudai.
- ISRM (1981). Basic Geotechnical Description for Rock Masses. *International Journal of Rock Mechanics, Mining Science and Geomechanics*, 18:85-110.
- Jamaluddin, T.A., Sian L.C. and Komoo, I. (2011). Laporan Terbuka Penyiasatan Geobencana Tanah Runtuh Madrasah Al-Taqwa, Felcra Sungai Semunggis, Batu 14, Hulu Langat, Selangor. *Institut Kajian Bencana Asia Tenggara (SEADPRI) Universiti Kebangsaan Malaysia*. 31.
- Janbu, N. (1968). Slope Stability Computations. *Soil Mech. Found. Engg. Report*, Trondheim Technical University of Norway.

- Janbu, N., Bjerrum, L. and Kjaernsli, B. (1956). Stabilitetsberegning for fyllinger skjaeringer og naturlige skraninger. *Norwegian Geotechnical Publication* No. 16, Oslo, Norway.
- Jennings, J.E. and Burland, J.B. (1962). Limitations to the Use of Effective Stresses in Partly Saturated Soils. *Geotechnique*. 12(2): 125-144.
- Jia, J., Zhou, C., Jiang, N. and Lu, S. (2014). Analysis of Stability of Residual Soil Slope and Treatment Measure. *Electronic Journal of Geotechnical Engineering*, 19, 3889-3898.
- Kong, T.B. and Kean, Y.C. (2002). Physico-chemical Properties of Andesitic Soils in the Kg. Awah Area, Pahang. *Geological Society of Malaysia Annual Geological Conference*. 31-35.
- Kong, T.B. and Miasin@Awang, S.F.E. (2005). Physico-Chemical Properties of Residual Soils of the Kenny Hill Formation in the Shah Alam Area, Selangor. *Geological Society of Malaysia Bulletin*. 51. 13-17.
- Krahn, J. (2004). Stability Modelling with SLOPE/W. *GEO-SLOPE/W International Ltd, Canada*.
- Lafayette, K.P.V., da Paz, D.H.F., Bezerra, J.d.S., and Coutinho, R.Q. (2014). Experimental Determination of Characteristic Curves of Soils Belonging to a Hillside in the Metropolitan Region of Recife/Brazil. *Electronic Journal of Geotechnical Engineering*. 19. 9873-9887.
- Lambe, T.W. and Whitman, R.V. (1969). Soil Mechanics. *Wiley, New York*, 363-365.
- Lee, M.L. (2008). *Influence of Rainfall Pattern on Suction Distribution and Slope Stability*. Doctor Philosophy. Universiti Teknologi Malaysia, Skudai.
- Leong, E.C. and Rahardjo, H. (1997). Permeability Functions for Unsaturated Soils. *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*. 123(12): 1118-1126.
- Lin, H. and Cao, P. (2012). Limit Equilibrium Analysis for the Relationships Among Slope c , ϕ and Slip Surface. *Electronic Journal of Geotechnical Engineering*. 17. 185-195.
- Little, A.L. (1969). The Engineering Classification of Residual Tropical Soils. *Proceedings 7th International Conference Soil Mechanics and Foundation Engineering, Mexico*, 1:1-10.
- Lowe, J. and Karafiath, L. (1960). Stability of Earth Dams Upon Drawdown. *Proc. 1st Pan-Am. Conf. Soil Mech. and Found. Engg.*, 537-552.
- Manna, B., Rawat, S., Zodinpuui, R. and Sharma, K.G. (2014). Effects of Surcharge Load on Stability of Slopes – Testing and Analysis. *Electronic Journal of Geotechnical Engineering*, 19, 3396-3410.
- Md. Noor, M.J. (2012). Understanding Rainfall-Induce Landslide. *Kuala Lumpur: Uitm Press*. 198.

- Mizal-Azzmi, N., Mohd-Noor, N. and Jamaludin, N. (2011). Geotechnical Approaches for Slope Stabilization in Residential Area. *The 2nd International Building Control Conference. Procedia Engineering 20*: 474-482.
- Moni, M.M. and Sazzad, M.M. (2015). Stability Analysis of Slopes with Surcharge by LEM and FEM. *International Journal of Advanced Structures and Geotechnical Engineering*, 04, 216-225.
- Morgenstern, N.R. and Price, V.E. (1965). The Analysis of the Stability of General Slip Surfaces. *Geotechnique*, 15(1), 70-93.
- Nazir, R., Ghareh, S., Mosallanezhad, M. and Moayedi, H. (2016) The Influence of Rainfall Intensity on Soil Mass from Cellular Confined Slopes. *Journal of Measurement*. 81. 13-25.
- Neves, M., Cavaleiro, V. and Pinto, A. (2016). Slope Stability Assessment and Evaluation of Remedial Measures Using Limit Equilibrium and Finite Element Approaches. *The 3rd International Conference on Transportation, Geotechnics (ICTG 2016), Procedia Engineering*, 143: 717-725.
- Niroumand, H., Kassim, K.A., Ghafooripour, A., Nazir, R. and Far, S.Y.Z. (2012). Investigation of Slope Failure in Soil Mechanics. *Electronic Journal of Geotechnical Engineering*, 17, 2703-2720.
- Niu, W.J. (2014). Determination of Slope Safety Factor with Analytical Solution and Searching Critical Slip Surface with Genetic-Traversal Random Method. *The Scientific World Journal*. 1-13.
- Oh, S. and Lu, N. (2015). Slope Stability Analysis under Unsaturated Conditions: Case Studies of Rainfall-Induced Failure of Cuts Slopes. *Engineering Geology*. 184. 96-103.
- Orense, R.P. (2012). Soil Liquefaction and Slope Failures During the 2011 Tohoku, Japan Earthquake. *2012 NZSEE Annual Technical Conference and AGM, New Zealand, 007*, 1-8.
- Ouadif, L., Bahi, L., Baba, K. and Akhssas, A. (2012). Study of Stability of a Highway Fill Application of the Analytical and the Finite Elements Methods. *International Journal of Engineering Research and Applications (IJERA)*. 2(1). 904-910.
- Paparo, M.A., Zaniboni, F. and Tinti, S. (2013). The Vajont Landslide, 9TH October 1963: Limit Equilibrium Model For Slope Stability Analysis through the Minimum Lithostatic Deviation Method. *Italian Journal of Engineering Geology and Environment*. (6). 583-592.
- Pramusandi, S., Rifa'I, A. and Suryolelono, K.B. (2015). Determination of Unsaturated Soil Properties and Slope Deformation Analysis Due to the Effect of Varies Rainfall. *The 5th International Conference of Euro Asia Civil Engineering Forum (EACEF-5), Procedia Engineering*, 125, 376-382.
- Prasetyowati, S.H. (2007). *Rainfall Characteristic Analysis Against the Slope Movement*. Master Thesis, Gadjah Mada University, Yogyakarta.

- Public Works Institute Malaysia (1996). Tropical Weathered In-Situ Materials. *Geoguides*: 1-5.
- Pushpa, K., Prasad, S.K. and Nanjundaswamy, P. (2017). Simplified Pseudostatic Analysis of Earthquake Induced Landslides. *Indian Journal of Advances in Chemical Sciences*/ 5(1). 54-58.
- Rahardjo, H., Aung, K.K., Leong, E.C. and Rezaur, R.B. (2004). Characteristics of Residual Soils in Singapore as Formed by Weathering. *Engineering Geology*. 73. 157-169.
- Rahardjo, H., Lim, T.T., Chang, M.F. and Fredlund, D.G. (1995). Shear Strength Characteristic of a Residual Soil. *Canadian Geotechnical Journal*, (32), 60-77.
- Rahman, M.Z. (2012). *Slope Stability Analysis and Road Safety Evaluation*. Master Thesis. Lulea University of Technology (LTU), Lulea, Sweden.
- Rees, S.W. and Ali, N. (2012). Tree Induced Soil Suction and Slope Stability. *Geomechanics and Geoengineering: An International Journal*. Taylor & Francis Group, London, Uk., 7, 103-113.
- Rongfu, X. and Gaopeng, T. (2015). Slope Stability Limit Analysis based on Inclined Slices Technique. *Electronic Journal of Geotechnical Engineering*. 20. 1813-1832.
- Rouaiguia, A. and Dahim, M.A. (2013). Numerical Modelling of Slope Stability Analysis. *International Journal of Engineering Science and Innovative Technology*. 2(3). 533-542.
- Salih, A.G. (2012). Review on Granitic Residual Soils Geotechnical Properties. *Electronic Journal of Geotechnical Engineering*, 2645-2658.
- Salween, S., Nayan, K.A.M and Murad, M.O.F (2016). Evaluation on the Stability of Slope at Faculty of Engineering and Built Environment (FKAB) using SLOPE/W. *Journal of Engineering*. 28. 79-86.
- Schnellmann, R., Rahardjo, H. and Schneider, H.R. (2013). Unsaturated Shear Strength of a Silty Sand. *Journal of Engineering Geology*. 162. 88-96.
- Shen, M.F., Tan, X.H., Xin, Z.Y., Xie, Y. and Xu, Q. (2013). Laboratory Research of Soil Water Characteristic Curve by Osmotic Method and Filter Paper Method. *Electronic Journal of Geotechnical Engineering*. 18. 5421-5434.
- Sokhanvar, M. and Kassim, A. (2013). Unsaturated Shear Strength Behaviour under Unconsolidated Undrained Tests. *Electronic Journal of Geotechnical Engineering*, 18, 601-612.
- Spencer, E. (1967). A Method of Analysis of the Stability of Embankments Assuming Parallel Interslice Forces. *Geotechnique*, 17(1), 11-26.
- Sun, D., Li, X., Feng, P. and Zang, Y. (2016). Stability Analysis of Unsaturated Soil Slope During Rainfall Infiltration Using Coupled Liquid-Gas-Soli Three-Phase Model. *Water Science and Engineering*. 9(3). 183-194.

- Taha, M.R., Hossain, M.K. and Mofiz, S.A. (2000) Behaviour and Modelling of Granite Residual Soil in Direct Shear Test. *Journal of Institution of Engineers Malaysia*. 61(2), 27-40.
- Tan, B.K. (1995). Some Experience on Weathering of Rocks and its Engineering Significance in Malaysia. *Ikram Geotechnical Meeting Workshop on Comparative Geotechnical Engineering Practice*. Novotel, Penang. Vol 2.
- Tan, B.K. (2004) Country Case Study: Engineering Geology of Tropical Residual Soils in Malaysia.
- Terzaghi, K. (1936). The Shear Resistance of Saturated Soils. *Proceedings 1st International Conference of Soil Mech., Found., Eng., Cambridge*, 1, 54-56.
- Townsend, F.C. (1985). Geotechnical Characteristics of Residual Soils. *Journal of Geotechnical Engineering*, 111, 77-92.
- Uchaipichat, A. (2012). Infinite Slope Stability Analysis for Unsaturated Granular Soils. *Electronic Journal of Geotechnical Engineering*, 361-368.
- Vanapalli, S.K. and Fredlund, D.G. (1997). Interpretation of Unsaturated Shear Strength of Unsaturated Soils in terms of Stress State Variables. *Proceedings of the 3rd Brazilian Symposium on Unsaturated Soils, Tacio de Campos, Vargas*, 35-45.
- Widger, R.A. (1976). *Slope Stability in Unsaturated Soils*. Master Thesis. University of Saskatchewan. Saskatchewan. Canada.
- Wu, T.H. (1995). Slope Stabilization. Slope Stabilization and Erosion Control: A Bioengineering Approach. *E & FN Spon*, 2-6 Boundary Row, London. 221-264.
- Zhai, Q., Rahardjo, H. and Satyanaga, A. (2016). Variability in Unsaturated Hydraulic Properties of Residual Soil in Singapore. *Engineering Geology*. 209. 21-29.
- Zhan, T.L.T. and Ng, C.W.W. (2004). Analytical Analysis of Rainfall Infiltration Mechanism in Unsaturated Soils. *International Journal of Geomechanics, ASCE*. 4(4): 273-284.
- Zhan-yong, G. and Jian-jun, D. (2014). Stability Analysis of Soil Slope under Changes of Unsaturated-Saturated State. *Electronic Journal of Geotechnical Engineering*. 19. 8485-8495.
- Zhang, G., Qian, Y., Wang, Z. and Zhao, B. (2014). Analysis of rainfall Infiltration Law in Unsaturated Soil Slope. *The Scientific World Journal*. 1-7.
- Zhang, L., Liu, J.H., Fu, H.Y. and Guo, Z. (2011). Analysis of Dynamic Stability of Rock Slope in Seismic Area in Sichuan Province. *Geotechnical Special Publication: Advances in Unsaturated Soils, Geo-Hazard, and Geo-Environmental Engineering 217*, 188-194.