DOI : https://doi.org/10.7186/wg503202403

Moisture retention characteristics of weathered graphitic-quartz-muscovite schist

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Abstract: Slope cuts in weathered graphitic-quartz-muscovite schist expose an upper pedological soil (3-4 m thick) of silty to sandy clays with lateritic concretions, and a lower saprock (>10 m thick) of alternating bands of variously colored, firm to stiff and hard, clayey silts and silts with indistinct to distinct relict bedrock minerals, textures and structures. Moderately sloping (<60°), low cuts (<15 m high) in unsaturated, weathered schist are unaffected by failures, though small slips and falls have sometimes occurred at steeper cuts during rainfall events. To validate the role of negative pore water pressures in influencing the stability of slope cuts, laboratory pressure plate tests were carried out on weathered graphitic-quartz-muscovite schist collected at depths of 5.83 m (A), 6.71 m (B) and 8.95 m (C) at a weathering profile in the Kajang Schist. Samples A, B, and C, with dry unit weights of 12.76, 14.73, and 13.23, kN/m^3, and porosities of 51%, 44%, and 49%, are overwhelmingly fine gained with silt contents of 53.6%, 73.7%, and 76.6%, and clay contents of 35.0%, 14.0%, and 23.0%, respectively. Increasing suctions from 0 kPa through 0.98 kPa and 9.8 kPa to 33 kPa and 1500 kPa resulted in volumetric moisture retentions of 49.9% through 48.9% and 36.7% to 33.0% and 7.2% in sample A, from 51.8% through 48.6% and 41.1% to 34.3% and 4.5% in sample B, and from 55.5% through 53.2% and 47.6% to 30.2% and 8.6% in sample C. Best fit lines drawn with the van Genuchten (1980) parametric model indicate rapidly decreasing moisture contents with increasing suction due to large porosities. It is concluded that negative pore water pressures in unsaturated, weathered graphitic-quartz-muscovite schist give rise to an enhanced shear strength and stability of slope cuts, though rapid infiltration of rainwater results in saturation and failure.

Keywords: Weathered graphitic-quartz-muscovite schist, moisture retention, suction, negative pore water pressures, slope cut stability

INTRODUCTION

Weathering profiles of considerable thickness are found in Peninsular Malaysia as a result of favorable tectonic and environmental factors that have permitted pervasive weathering of bedrock during a larger part of the Cenozoic era (Raj, 2009). The weathered materials are characterized by indistinct to distinct preservation of the minerals, textures and structures of the original bedrock and are classified as residual soils for they can removed by commonly accepted excavating methods (USBR, 1974; JKR, 2007). In undulating to hilly terrain in the Peninsula, residual soils are considered to be unsaturated for unconfined groundwater tables are only found at great depths (Bujang *et al*., 2005; Raj, 2009).

Unsaturated soils are characterized by negative pore water pressures or suction; the relationship between moisture content and suction best described by the soil water characteristic curve (Agus *et al*., 2001). In Agronomy, the soil water characteristic curve is known as the soil moisture retention curve and is important for developing effective irrigation and plant stress management techniques as the yield and quality of crops is influenced by suction/water relationships (Scherer *et al*., 1996).

In a study to characterize the fertility of saprolite layers (C soil horizon) as agricultural substrates, Hamdan *et al*. (1998) investigated three weathered rock-saprolite-soil sequences over basalt, granite and schist in Peninsular Malaysia. The three sequences were differentiated into several horizons, morphologically described and sampled for determination of various physical and chemical properties, including granulometry, porosity and moisture retention characteristics as well as pH, organic carbon contents and cation exchange capacity. The study concluded that the saprolites were of poor fertility and could pose a serious limitation to crop production in upland soil areas (Hamdan *et al*., 1998).

0126-5539; 2682-7549 / Published by the Geological Society of Malaysia.

Noguchi *et al*. (2003) determined the depths, saturated hydraulic conductivity and moisture retention curves of soils developed over meta-sedimentary bedrock at a site in tropical rain forest, and at a site in a nearby rubber plantation. Total soil depths at the forest site were between 118 and 140 cm, and those in the rubber estate, between 106 and 162 cm, whilst the macro-porosity varied from 3.0% to 13.9% at the forest site, and from 2.7% to 7.7% at the rubber plantation. Noguchi *et al*. (2003) concluded that the study allowed a better understanding of the influence of land-use on water conservation.

Hamdan *et al*. (2006) employed the pressure plate method to determine the soil moisture retention curves of granite, basalt, schist and shale saprolites in Peninsular Malaysia as part of a study to evaluate their hydraulic conductivity. In the case of the schist saprolite, increasing suctions from 0 kPa through 0.98 kPa and 9.8 kPa to 33 kPa and 1500 kPa resulted in volumetric moisture retentions of 78% through 47% and 45% to 39% and 19%.

Soil water characteristic curves of a red laterite soil compacted at three different moisture contents, i.e., dry of optimum, optimum, and wet of optimum, were determined with the pressure plate method by Yamusa *et al*. (2019). After applying different parametric models to obtain curve fitting parameters, Yamusa *et al*. (2019) concluded that the van Genuchten (1980) as well as Fredlund & Xing (1994) models could fit most of the curves, though the Brooks & Corey (1964) model represented the curves better when the soil had a distinct air entry suction.

In an earlier study, it was reported that moderately sloping (<60°), low cuts (<15 m high) in weathered graphitic-quartz-muscovite schist in the Kajang area were unaffected by failure where they were located above unconfined groundwater tables (Raj, 2001). Where the low cuts were excavated at steeper angles (>60°), however, there had sometimes occurred small earth falls and shallow slips during, or following, periods of continuous rainfall (Raj, 2001). As the cuts involved unsaturated earth materials, it was considered that negative pore water pressures (or suction) contributed to their stability through enhanced shear strengths, though infiltration of rainwater led to saturation and loss of the enhanced strength (Raj, 2001).

The role of negative pore water pressures (or suction) in enhancing the stability of slope cuts in the residual soils of humid tropical areas and the occurrence of failures during periods of rainfall have been high-lighted by several workers, in particular Wesley (2009; 2010; 2011). Yusof *et al*. (2016) furthermore, have concluded that it is the infiltration of rainfall in Malaysia that results in slope failures due to loss of the negative pore water pressures (or suction) that provides an additional shear strength to unsaturated soils. The soil water retention (or soil water characteristic) curve was thus considered to be the key to implementation of unsaturated soil mechanics in engineering practice in Malaysia (Yusof *et al*., 2016).

In this geological short note, are discussed the results of laboratory pressure plate tests that were carried out to validate the presence of negative pore water pressures (or suction) in unsaturated, weathered graphitic-quartz-muscovite schist, and their influence on the stability of slope cuts.

GEOLOGICAL SETTING

In the Kajang area are found dark grey to black, graphitic-quartz-muscovite schists inter-layered with thin bands and lenses of orange to buff, quartz-muscovite schists (Figure 1). These schists, mapped as the Kajang Schist, are of a probable Silurian to Devonian age and strongly folded with many quartz veins and pods (Yin, 1976; Lee, 2009). Thin-section and binocular microscope descriptions of these graphitic-quartz-muscovite schists have been earlier published (Raj, 1995).

The Kajang Schist is deeply weathered with slope cut exposures showing two broad weathering zones; i.e. an upper pedological soil and a lower saprock (Raj, 1995). The pedological soil, which comprises silty to

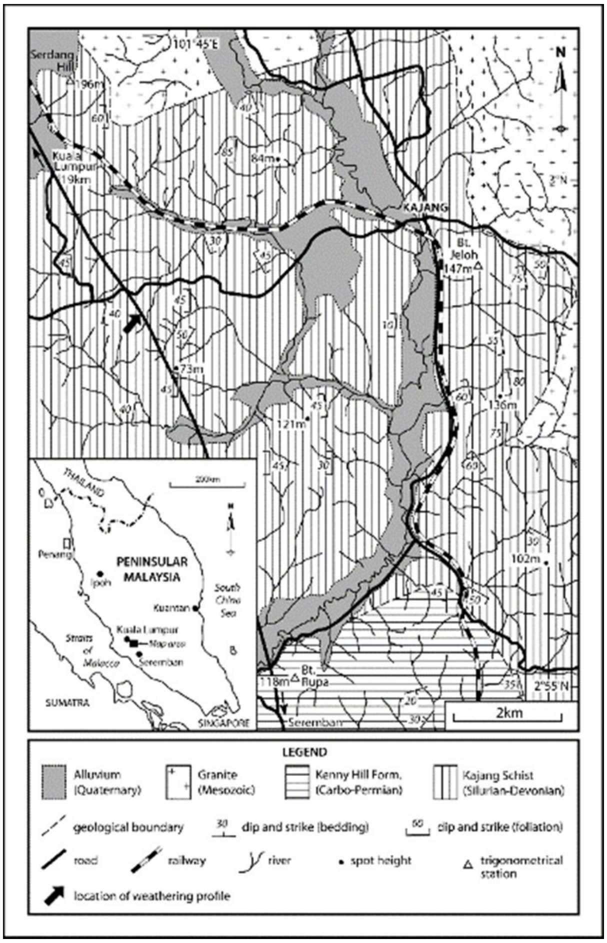

Figure 1: Geology map of the Kajang area (main roads in 1985) showing location of sampled weathering profile. (After Yin, 1976).

sandy clays with abundant lateritic concretions, is some 3 to 4 m thick and can be separated into B and C soil horizons. The saprock is more than 10 m thick and consists of alternating bands of variously colored, firm to stiff and hard, clayey silts and silts with indistinct to distinct preservation of the original bedrock minerals, textures and structures (Raj, 1995).

A field survey of slope cuts in the Kajang Schist has shown that failures have not occurred at moderately sloping (<60°), low cuts (<15 m high), located above unconfined groundwater tables (Raj, 2001). These cuts were considered to be excavated in unsaturated earth materials that are characterized by negative pore water pressures (or suction); a feature that gives rise to the enhanced shear strength of residual soils in humid tropical areas (Wesley, 2009; Wesley, 2010; Wesley, 2011).

Where the low cuts were excavated at steeper angles (>60°), however, there have sometimes occurred, during or following periods of rainfall, failures that are best classified as earth falls and shallow slips (Raj, 2001). The earth falls, which involved small volumes (<2 m^3) of pedological soil, only occurred at very steep cuts (>80°) and were preceded by the development of tension cracks. Infiltration of rainwater through the tension cracks was considered to result in the loss of negative pore water pressures and down-slope movement of a small saturated soil mass backed by the tension crack (Raj, 2001). The shallow slips involved small volumes (<3 m^3) of pedological soil and/or highly to completely weathered schist (saprock), and were preceded by the development of desiccation (or shrinkage) cracks (Raj, 2001). Infiltration of rainwater through the cracks thus led to saturation, and loss of negative pore water pressures, which then led to sliding of a small, saturated soil mass along an approximately cylindrical surface (Raj, 2001).

METHODOLOGY

In order to validate the presence of negative pore water pressures in unsaturated, weathered graphitic-quartz-muscovite schist, samples were collected for determination of their moisture retention characteristics through laboratory pressure plate tests. The samples were collected at the weathering profile in Kajang Schist exposed at the slope cut at Km 298.30 (south bound) of the N-S Expressway (Figure 1).

The slope cut is located in undulating terrain with several low hills and ridges (rising to some 160 m above sea-level) separated by narrow to broad, flat-bottomed valleys (some 15 m above sea-level). The cut itself is excavated where the N-S trending Expressway crosses a low ridge rising to 65 m above sea-level. The cut with a vertical height of 10 m and overall angle of 45° is benched; the 2.50 m and 3.75 m high benches with 55° face angles, separated by 1.56 m, and 1.88 m, wide horizontal berms (Figure 2).

Brass rings of 4 cm length and 7.6 cm internal diameter were used to collect the samples at vertical depths of 5.83 m (sample A), 6.71 m (sample B) and 8.95 m (sample C) at the selected profile (Figures 2 & 3). Two constant volume samples were collected at each sampling point; one for determination of physical and soil index properties, and the other for determination of the water retention characteristics. Details on the method of sampling have been described in earlier publications (Raj, 2010; 2021).

Subsequent treatment of the undisturbed samples for determination of their physical and soil index properties according to standard procedures (ASTM, 1970) has also been described in earlier publications (Raj, 2021; 2023). Laboratory determinations of the moisture retention characteristics of the weathered graphitic-quartz-muscovite schist were carried out according to standard

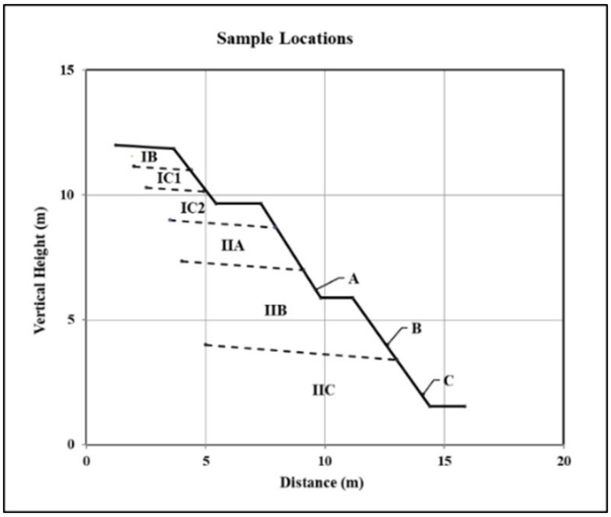

Figure 2: Sample locations and lateral extensions of weathering sub-zones.
(Note: IB refers to soil horizon B, IC1 and IC2 refer to soil horizon C, and IIA, IIB and IIC refer to weathering sub-zones within saprock).

Figure 3: View of slope cut with sampling locations.

procedure described in earlier publications (Raj, 2021; 2023). Results of these laboratory determinations were used to plot volumetric moisture retention curves (or water characteristic curves) and best-fit lines drawn with the van Genuchten (1980) parametric function.

RESULTS

Descriptions of weathered graphitic-quartz-muscovite samples

As earth materials in weathering profiles preserve to different extents, the minerals, textures and structures of the original bedrock material and mass, it is important that samples for field or laboratory tests be described in as much detail as possible (Raj, 1983; Raj, 2009). In the case of the present samples, some minor differences in color, texture and mineral composition are seen as they were collected at different depths (Table 1).

Relict foliation planes resulting from the alignment of silt and clay sized particles are present in all three samples; the shallower samples (A and B) being lighter colored than the deeper sample (C). The coarse fractions of samples A and B consist of sericite flakes and some quartz grains, though sample C only comprises sericite flakes. The clay fractions of all samples are similar in composition; the clay minerals present being kaolinite and illite (Raj, 1995).

Physical and soil index properties of weathered graphitic-quartz-muscovite schist

The three samples show minor differences in physical properties; samples A, B, and C, having dry unit weights of 12.76, 14.73, and 13.25, kN/m^3, and dry densities of 1301, 1502, and 1349 kg/m^3, respectively (Table 2). Samples A, B, and C, have field moisture contents of 33.1%, 26.7%, and 34.0%, respectively, whilst the specific gravity of their soil particles is closely similar (2.67-2.68) due to fairly similar mineral compositions (Table 1). Samples A, B and C also have porosities of 51%, 44% and 49%, and void ratios of 1.05, 0.79, and 0.98, respectively (Table 2). Plastic limits of samples A, B and C are some 37%, 33% and 35%, whilst liquid limits are 50%, 43% and 50%, respectively.

Some variations in soil texture result from differences in sampling depths; samples B and C with an absence of gravel fractions and sample A with a very small gravel fraction (2.2%) (Table 2). Sample C has a very minor sand content (0.4%), whilst samples A, and B, have contents of 10.2%, and 12.3%, respectively. Fine grained fractions are very variable; samples A, B and C with silt contents of 52.6%, 73.7%, and 76.6%, and clay contents of 35.0%, 14.0% and 23.0%, respectively. Relatively large silt contents thus characterize the deeper samples (B and C), whilst relatively large clay contents characterize the shallower sample A (Table 2).

Pressure plate tests on weathered graphitic-quartz-muscovite schist samples

Volumetric moisture contents are seen to decrease with increasing suctions in the laboratory pressure plate tests (m). In sample A, volumetric moisture contents decrease from 49.9% through 48.9% and 36.7% to 33.9% and 7.2% under increasing suctions from 0 kPa through

Table 1: Descriptions of weathered schist samples.

Sample	Sub-zone	Vertical Depth	Description
A	IIB	5.83 m	Light grey, firm, clayey silt with distinct relict foliation. Coarse fraction of quartz grains & sericite flakes. Clay fraction of kaolinite & illite. Highly weathered graphitic-quartz- muscovite schist.
B	IIB	6.71 m	Light grey, firm, silt with distinct relict foliation. Coarse fraction of quartz grains & sericite flakes. Clay fraction of kaolinite & illite. Highly weathered graphitic-quartz-muscovite schist.
C	IIC	8.95 m	Dark grey, stiff, clayey silt with distinct relict foliation. Coarse fraction of sericite flakes. Clay fraction of kaolinite & illite. Moderately weathered graphitic-quartz-muscovite schist.

Table 2: Physical and soil index properties of weathered schist samples.

Sample	Depth (m)	Dry Density (kg/m^3)	Mineral Grain SG	Porosity (%)	Void Ratio	Gravel (%)	Sand (%)	Silt (%)	Clay (%)
A	5.83	1301	2.67	51	1.05	2.2	10.2	52.6	35.0
B	6.71	1501	2.68	44	0.79	0.0	12.3	73.7	14.0
C	8.95	1349	2.67	49	0.98	0.0	0.4	76.6	23.0

Note: SG refers to Specific Gravity

0.98 kPa and 9.8 kPa to 33 kPa and 1500 kPa, respectively (Table 3). Exactly similar increasing suctions furthermore, give rise to decreasing volumetric moisture contents from 51.8% through 48.6% and 41.1% to 34.3% and 4.5% in sample B, and from 55.5% through 53.2% and 47.6% to 30.2% and 8.6% in sample C (Table 3).

Plots of volumetric moisture content versus suction pressure for samples A, B and C are shown in Figures 4, 5 and 6 together with the best fit lines calculated with the van Genuchten (1980) parametric function. The best fit-lines are bilinear in nature with an initially horizontal segment followed by a steeply sloping segment.

Available water storage capacity of weathered graphitic-quartz-muscovite schist

Laboratory pressure plate tests yield four levels of moisture content that reflect the availability of water in soil to plants, i.e., a) saturation, b) field capacity, c) wilting point, and d) oven dry (Scherer *et al*., 1996). The moisture content when all pores in the soil are filled with water is known as saturation, whilst the field capacity refers to the moisture content left in a soil after drainage of gravitational water (Scherer *et al*., 1996). The wilting point is defined as the moisture content where most plants cannot exert enough force to remove water from small pores in the soil. When soil is dried in an oven nearly all water is removed; this "oven dry" moisture content providing a reference for measuring the other three moisture contents (Scherer *et al*., 1996).

At saturation, there is a soil moisture tension of about 0.001 bar (0.1 kPa) or less, whilst at field capacity, most soils have a soil moisture tension between 0.05 and 0.33 bars (5 and 33 kPa) (Scherer *et al*., 1996). The wilting

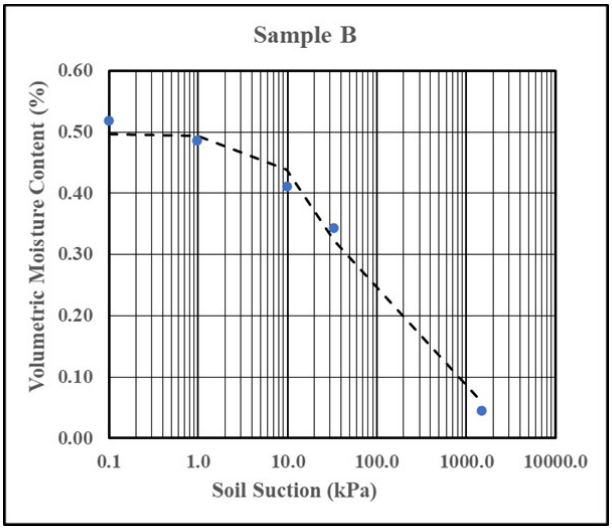

Figure 5: Moisture retention curve of sample B with best fit line based on van Genuchten (1980) parametric model.

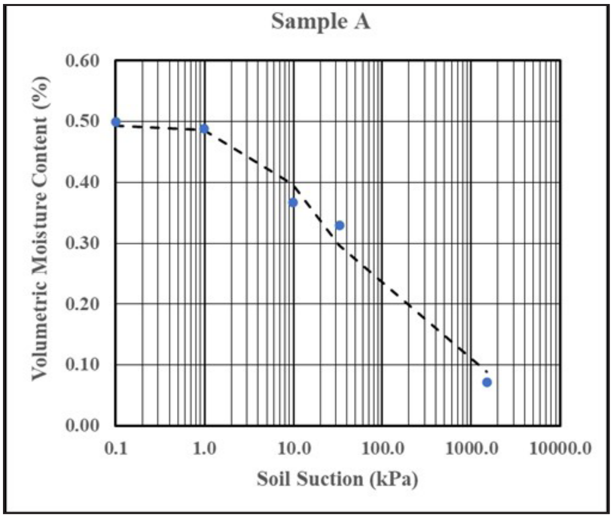

Figure 4: Moisture retention curve of sample A with best fit line based on van Genuchten (1980) parametric model.

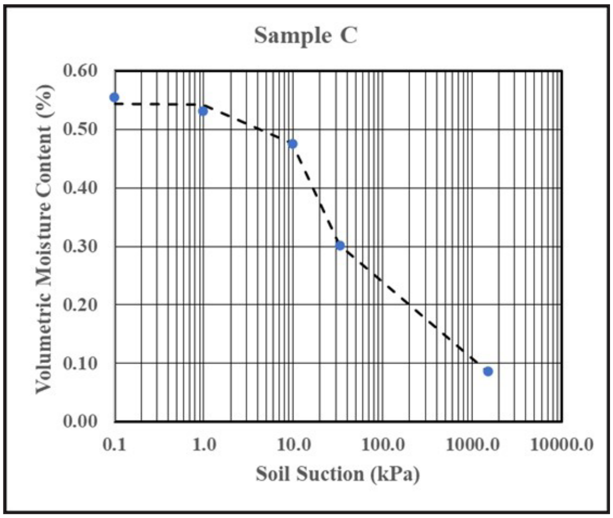

Figure 6: Moisture retention curve of sample C with best fit line based on van Genuchten (1980) parametric model.

Table 3: Volumetric moisture contents retained under different suctions.

Sample	Vertical depth	Volumetric moisture content (%)				
		0 kPa	0.98 kPa	9.8 kPa	33 kPa	1500 kPa
A	5.83	49.9	48.9	36.7	33.0	7.2
B	6.71	51.8	48.6	41.1	34.3	4.5
C	8.95	55.5	53.2	47.6	30.2	8.6

point for most agricultural crops furthermore, is at about 15 bars (1,500 kPa) of soil moisture tension (Scherer *et al*., 1996). The difference between the amount of water in the soil at field capacity and the amount at the permanent wilting point is referred to as available soil moisture or available water storage capacity (Weiler & McDonnell, 2004). Based on these definitions, the weathered graphitic-quartz-muscovite schist has the water storage capacities shown in Table 4.

DISCUSSION

Published data on physical and soil index properties of weathered schist

Published data of direct relevance to physical and soil index properties of the present samples are those cited in the study to characterize the fertility of saprolites in the Peninsula (Hamdan *et al*., 1998). Relevant results (Table 5) show the present samples (Table 2) to have fairly similar physical and soil index properties as those from the lower saprolite and saprock of a weathering profile over schist. Details of the type of schist are not known, though the sampling location at a road cut in Selangor or Pahang suggests a quartz-mica schist.

The physical and soil index properties of the present samples are also comparable with those reported for a schist saprolite which had a bulk density of 1300 kg/m^3, particle density of 2300 kg/m^3, moisture content of 15.6% and total porosity of 42% (Hamdan *et al*., 2006).

Published data on pressure plate tests of weathered schist

Published data of direct relevance to the present tests are those cited in the study to characterize the fertility of saprolites in the Peninsula (Hamdan *et al*., 1998). Relevant results (Table 5) show the volumetric moisture retentions of a schist saprock to be relatively similar to those determined in the present study (Table 3). Somewhat similar volumetric moisture retentions are also reported in the study to evaluate the hydraulic conductivity of a schist saprolite (Hamdan *et al*., 2006) where increasing suctions from 0 kPa through 0.98 kPa and 9.8 kPa to 33 kPa and 1500 kPa resulted in volumetric moisture contents of 78% through 47% and 45% to 39% and 19%. The results are not exactly similar with those of the present study (Table 3) as there are differences in texture between samples from saprolite, and those from saprock.

The plots of moisture retention curves with best fit lines of the present study should ideally be compared with those involving similar earth materials as the study by Noguchi *et al*. (2003). In the study of Noguchi *et al*. (2003), pressure plate tests were carried out on soils over meta-sedimentary bedrock at a site in tropical rain forest, and at a site in a nearby rubber plantation. Two types of best fit lines were obtained with the van Genuchten (1980) parametric model; both with an initially horizonal segment, but followed by a steeply sloping segment in the first type, and a gently sloping segment in the second type. These differences, which indicate rapid, or gradual, decreases in moisture content with increasing suction, were considered to reflect differences in the volumes of mesopores and macropores (Noguchi *et al*., 2003). Best fit lines plotted in the present study (Figures 4, 5 and 6) are similar to those of the first type of Noguchi *et al*. (2003) and indicate a rapid decrease in moisture content with increasing suction due to a large volume of mesopores and macropores. The rapid decrease in moisture content with increasing suction also reflects the inherent alignment of silt-sized particles in the present samples as they were collected from saprock where indistinct to distinct relict foliation planes are present.

Table 4: Available water storage capacity of weathered schist samples.

Sample	Depth (m)	Saturation (%)	Field Capacity (%)	Wilting Point (%)	Available Water Storage Capacity (%)
A	5.83	49.9	33.0	7.2	25.8
B	6.71	51.8	34.3	4.5	29.8
C	8.95	55.5	30.2	8.6	21.6

Table 5: Soil index properties and moisture retention contents under different suctions of a schist saprolite and saprock (From Tables 1 & 2 in Hamdan *et al*., 1998).

Horizon	Depth (m)	Bulk Density (kg/m^3)	Porosity (%)	Granulometry			Volumetric moisture content (%)				
				Clay (%)	Silt (%)	Sand (%)	0 kPa	0.98 kPa	9.8 kPa	33 kPa	1500 kPa
Upper Saprolite	1.5 – 6	1590	44.8	39.4	43.2	17.5	72.0	66.5	45.9	42.1	12.4
Lower Saprolite	6 – 9	1850	49.3	10.9	79.1	11.0	88.7	60.2	57.1	42.2	10.3
Saprock	9 – 10	1950	45.8	7.4	81.7	10.9	52.9	51.2	40.6	23.2	11.1

The best fit lines of the present study (Figures 4, 5 and 6) are also very similar to those shown in the study by Yamusa *et al*. (2019) where pressure plate tests were carried out on three specimens of a red laterite soil moulded at 2% dry of optimum, at optimum, and 2% wet of optimum, water content. The similarity in shape of the best fit lines again points to the rapid decrease in moisture content with increasing suction due to a relatively large volume of mesopores and macropores.

Published data on available water storage capacity of weathered schist

Available water storage capacities (21.6% to 29.8%) of the present samples (Table 4) are best correlated with the average values of 20% and 21% for loam and silt loam soils cited by Easton & Bock (2016). The values of field capacity (30.2% to 34.3%) (Table 4) can also be correlated with the average values of 36% and 39% for loam and silt loam soils noted by Easton & Bock (2016). The moisture contents at wilting point (4.5% to 8.6%), however, are much lower than the average values of 16% and 18% cited for loam and silt loam soils, and are probably best correlated with the average value of 9% cited for a sandy loam (Easton & Bock, 2016).

Locally published data of direct relevance to the available water storage capacities (21.6% to 29.8%) of the present samples are those cited for samples from lower saprolite (42.2%), and from saprock (23.2%), at a profile over schist (Hamdan *et al*., 1998). The moisture contents at wilting point for these samples from lower saprolite (10.3%), and saprock (11.1%), however, are larger than those determined in the present study. This difference may be attributed to differences in texture as well as the extent of preservation of relict foliation planes.

Significance of study

The role of negative pore water pressures in enhancing the stability of slope cuts in the residual soils of humid tropical areas and the occurrence of failures during periods of rainfall has been high-lighted by several workers, including Wesley (2009), Wesley (2010), Rahardjo *et al*. (2010) and Wesley (2011). Yusof *et al*. (2016) have also concluded that in Malaysia, it is the infiltration of rainfall that results in slope failures due to the loss of the negative pore water pressures or soil suction that provide an additional shear strength in unsaturated soils. This additional shear strength is best described as being the contractile skin or air–water interface (Fredlund & Morgenstern, 1977) that acts like an elastic membrane and influences the mechanical behavior of soil by pulling the soil particles together through surface tension (Rahardjo *et al*., 2019).

In the present study, it has been shown that decreasing moisture contents in weathered graphitic-quartz-muscovite schist are reflected by increasing suctions (or negative pore water pressures). These negative pore water pressures thus account for the absence of failures at moderately sloping, low cuts in unsaturated, weathered graphitic-quartz-muscovite schist as they give rise to enhanced (or additional) shear strengths.

Best fit lines plotted with the van Genuchten (1980) parametric model in the present study furthermore, show initially horizontal segments followed by steeply sloping segments that indicate rapid decreases in moisture contents with increasing suction (or negative pore water pressures). Infiltration of rainwater will thus give rise to a rapid decrease of negative pore water pressures and loss of the additional shear strength. This feature thus accounts for the earth falls and shallow slips that have occurred at steeply sloping, low cuts in unsaturated, weathered graphitic-quartz-muscovite schist; infiltration of rainwater aided by the tension and desiccation cracks that were earlier formed.

CONCLUSIONS

Samples, collected at depths of 5.83 m (A), 6.71 m (B) and 8.95 m (C) at a weathering profile in weathered graphitic-quartz-muscovite schist, have dry unit weights of 12.76, 14.73, and 13.23, kN/m^3, and dry densities of 1301, 1501, and 1349, kg/m^3, respectively. Samples A, B and C have porosities of 51%, 44%, and 49%, and void ratios of 1.05, 0.79 and 0.98, respectively whilst their constituent mineral grains have a specific gravity between 2.67 and 2.68. Grain size analyses show samples A, B and C to be overwhelmingly fine-grained with silt contents of 53.6%, 73.7%, and 76.6%, and clay contents of 35.0%, 14.0%, and 23.0%, respectively.

Laboratory determinations employing the pressure plate method show increasing suctions from 0 kPa through 0.98 kPa and 9.8 kPa to 33 kPa and 1,500 kPa, to result in volumetric moisture retentions of 49.9% through 48.9% and 36.7% to 33.0% and 7.2% in sample A, from 51.8% through 48.6% and 41.1% to 34.3% and 4.5% in sample B, and from 55.5% through 53.2% and 47.6% to 30.2% and 8.6% in sample C.

Decreasing moisture contents with increasing suctions indicate the presence of negative pore water pressures; a feature that gives rise to enhanced shear strengths and accounts for the absence of failures at moderately sloping (<60°), low (<15 m height) cuts in unsaturated, weathered graphitic-quartz-muscovite schist.

Best fit lines plotted with the van Genuchten (1980) parametric model for the moisture retention (or water characteristic) curves show an initial horizontal segment followed by a steeply sloping segment indicating a rapid decrease in moisture content with increasing suction due to large porosities. Infiltration of rainwater thus results in a rapid decrease in negative pore water pressures and the loss of enhanced shear strength which gives rise to the earth falls and shallow slips at steeply sloping, low cuts in unsaturated, weathered graphitic-quartz-muscovite schists.

ACKNOWLDEGEMENTS

The study was supported by an F-Vote Research Grant from the University of Malaya. Grateful thanks are extended to the two anonymous reviewers for their valuable comments.

CONFLICTS OF INTEREST

The author has no conflicts of interest to declare that are relevant to the contents of this article.

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Manuscript received 26 March 2024;
Received in revised form 27 May 2024;
Accepted 1 July 2024
Available online 30 December 2024