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UNDRAINED SHEAR STRENGTH PARAMETERS OF SAPROCK FROM A WEATHERING PROFILE OVER PORPHYRITIC BIOTITE GRANITE AT KM 31 OF THE KUALA LUMPUR - KARAK HIGHWAY, PENINSULAR MALAYSIA

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Abstract

Three broad zones can be differentiated at the weathering profile; an upper, 9.4 m thick, pedological soil (zone I), an intermediate, 31.7 m thick, saprock (zone II) and the bottom bedrock (zone III). The saprock (zone II) comprises gravelly silty sands that distinctly preserve the minerals, textures and structures of the original granite and can be separated into sub-zones II A, II B, II C, and II D, based on differences in preservation of relict structures and content of litho-relicts (core-boulders). To characterize the undrained strength of saprock, samples were collected from sub-zones II A, II B, II C and II D and their physical and soil index properties determined before unconsolidated undrained triaxial tests were carried out on remolded samples. Three to four individual samples from each sub-zone were compressed under confining pressures of 138 kPa, 207 kPa, 276 kPa and/or 345 kPa. Plots of pf = [(σ1 + σ3)/2] versus qf = [(σ1 - σ3)/2] were then used to calculate apparent cohesions of 41.9 kPa, 100.3 kPa, 76.1 kPa and 73.9 kPa, and friction angles of 32.2^o, 28.1^o, 26.6^o and 27.8^o, for the samples from sub-zones II A, II B, II C, and II D, respectively.
Regression analyses show apparent cohesions to decrease with increasing clay contents, and degrees of saturation; features indicating the influence of negative pore water (or suction) pressures. Regression analyses also show apparent friction angle to increase with increasing sand contents; a feature attributed to greater inter-locking and resistance to displacement of these particles. It is concluded that the undrained shear strength parameters of saprock are characterized by an average apparent cohesion of 54.6 kPa, and friction angle of 30.5o; the parameters influenced by the degree of saturation as well as clay and sand contents.

Keywords: Unconsolidated undrained triaxial tests; saprock; weathering profile over granite; apparent cohesion; friction angle

1.0 INTRODUCTION

Weathering profiles are found in most parts of the world and show variable patterns and thicknesses for the rates, depths and courses of weathering are influenced by several factors, including climatic, biotic, geomorphic, site, geologic and chronologic ones (Thomas, 1974). As weathering occurs in situ, the weathered materials accumulate at the sites of formation and give rise to thick mantles of weathered materials (or regolith) over bedrock. The regoliths show variations in the extent of preservation of the minerals, textures and structures of the original bedrock; the vertical sequence of materials of different composition extending up to the ground surface from the unaltered bedrock below known as the weathering profile (Dearman, 1974; Raj, 2009).

Deep weathering profiles are found in Peninsular Malaysia as a result of favorable tectonic and environmental settings that have facilitated prolonged and pervasive chemical weathering throughout most of the Cenozoic Era (Raj, 2009). The earth materials in these weathering profiles are classified as 'residual soils' in geotechnical literature and said to have characteristics that are quite different from those of 'transported or sedimentary soils' (Tan and Gue, 2001; Wesley, 2009). As unconfined groundwater tables in the hilly to mountainous terrain of Peninsular Malaysia are located at depth (several tens of meters below the ground surface), the 'residual soils' are also known as 'unsaturated soils' that are characterized by negative pore water pressures (or suction) (Faisal et al., 2005).

'Residual soils' are said to be of a very heterogeneous nature which makes the sampling and testing of representative parameters difficult, whilst their usually high permeability makes them susceptible to rapid changes in material properties when subjected to changes of external hydraulic condition (Tan and Gue, 2001). The shear strength parameters of 'residual soils' in tropical areas are also said to be generally higher than those of 'sedimentary soils' (Wesley, 2009). It has thus been pointed out that it is rare for the undrained strength of 'residual soils' to be less than about 75 kPa, whilst their effective friction angles are generally above 30° with significant values of effective cohesion (Wesley, 2009). Disturbed samples of 'residual soils' furthermore, are said to yield lower shear strengths due to a collapse in soil structure (Salih, 2012).

There is limited published data on the undrained and drained shear strength parameters of earth materials in weathering profiles over different bedrock in Malaysia, especially those over granitic bedrock. In a review of 'residual soils' over granite in Peninsular Malaysia, it was concluded that "the degree of weathering process and clay content" have a significant influence on their engineering properties; the properties being similar at the same subsurface level, but varying with depth (Salih, 2012). In the case of unconsolidated undrained (from henceforth symbolized as UU) triaxial tests, apparent cohesions between 61.8 and 117 kN/m^2, and friction angles of 1° to 9.5°, have been reported for a residual soil over granite treated as a sand-silt-clay composite mixture (Ting and Ooi, 1976). UU triaxial tests on samples at a depth of 15 m in a residual soil over granite furthermore, yielded apparent cohesions between 27 and 87 kPa, and friction angles of less than 11° (Todo and Fauzi, 1989). Similar tests on a remolded gravelly silt (collected at a depth of 1.5 m in Skudai, Johore), yielded apparent cohesions of 10 to 13 kPa, and friction angles of 31° to 35° (Salih and Kassim, 2012).

In the course of a study on the characterization of weathering profiles in Peninsular Malaysia was investigated the profile over porphyritic biotite granite at Km 31 of the Kuala Lumpur - Karak Highway (Raj, 1983). The characterization of this profile based on field mapping and differentiation of morphological zones and sub-zones followed by laboratory determination of their physical and soil index properties has been earlier discussed (Raj, 1985). The soil-moisture retention characteristics of earth materials in the said weathering profile as well as their saturated hydraulic conductivity have also been earlier discussed (Raj, 2010; Raj, in press). In this paper are discussed the results of UU triaxial tests that were carried out to determine the undrained strength parameters of earth materials in the weathering profile and the factors influencing them (the parameters).

2.0 METHODOLOGY

The investigated weathering profile is located at the slope cut at Km 31 of the Kuala Lumpur - Karak Highway and was exposed during earthworks for construction of the Highway (Figure 1). Field mapping was first carried out to visually differentiate morphological zones and sub-zones, followed by the collection of constant volume samples at various depths to determine the physical and soil index properties of the earth materials present (Raj, 1985).

Samples for triaxial tests were collected with stainless steel tubes of 20.3 cm length and 4.06 cm internal diameter at four different locations in the weathering profile (Figure 2). The tubes had a constant wall thickness of 0.2 cm except towards one end, where the wall tapered to provide a cutting edge. Prior to sampling, the tubes were externally greased to facilitate entry, whilst materials on the slope were cleared to a depth of some 0.5 m to minimize surface effects. Each of the sampling tubes was driven into the soil by gently hammering on a block of wood placed on its top and then retrieved by removing the surrounding, and underlying, soil. Three to four tube samples were collected at every location together with samples for determination of the physical and soil index properties of the saprock. A mechanical core extruder was used to retrieve the individual specimens which mostly disaggregated on extrusion. Remolded specimens were then prepared by compacting the disaggregated material (to field density and moisture content) in a constant volume mold of 3.81 cm internal diameter and 7.62 cm height.

Individual specimens were weighed, capped at their top, and bottom, ends with perspex discs and then enclosed in a close-fitting rubber membrane. The specimens were sealed with O-rings placed around the top and bottom discs and then mounted on the pedestal of the triaxial cell. The enclosing perspex cylinder was screwed onto the base, filled with distilled water and placed under a specified pressure according to standard procedure (Bishop and Henkel, 1957). The specimens were compressed at a constant rate of 1.219 mm/min (0.048 in/min); load gauge readings being recorded at specified compression gauge values. Compression was usually stopped when an axial strain of 20% was reached; the cell pressure reduced and water drained to describe the sample after test.

Three (and in one case four) individual specimens of each sample set were tested under different confining pressures as multi-stage testing of single samples was said to produce misleading results (Tan and Gue, 2001). The deviator stress ($\sigma 1 - \sigma 3$) versus axial strain for each of the individual tests was plotted and a Mohr circle then drawn to represent the state-of-stress at the peak value. The values of $pf = [(\sigma 1 + \sigma 3)/2]$ and $qf = [(\sigma 1 - \sigma 3)/2]$ corresponding to the peaks of the stress-strain curves of the individual specimens from each sample set were then plotted. The line drawn through the points is known as the Kf line; its gradient (ά) and intercept (a) used to calculate the shear strength parameters of apparent cohesion (c) and apparent angle of friction (ϕ) (Lambe and Whitman, 1973).

It is to be noted that the proving rings and other equipment employed in the triaxial tests were calibrated in Imperial (or British) System units. Correlation factors were thus applied to the original measurements in order to convert them to SI (System International) units.

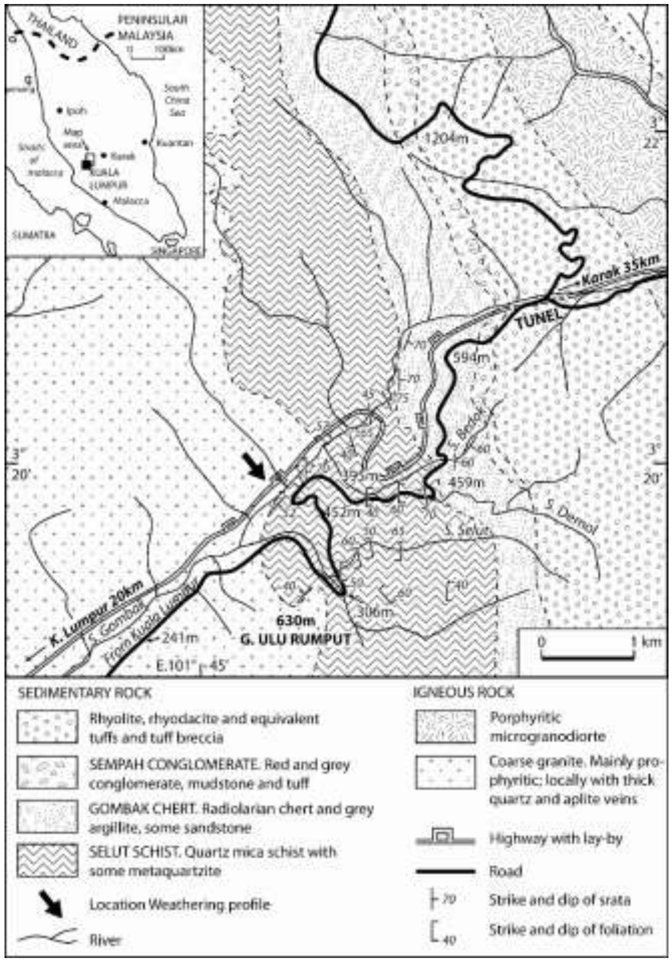

Figure 1 Geology map of the Genting Sempah area, Pahang and Selangor (Haile et al., 1977).

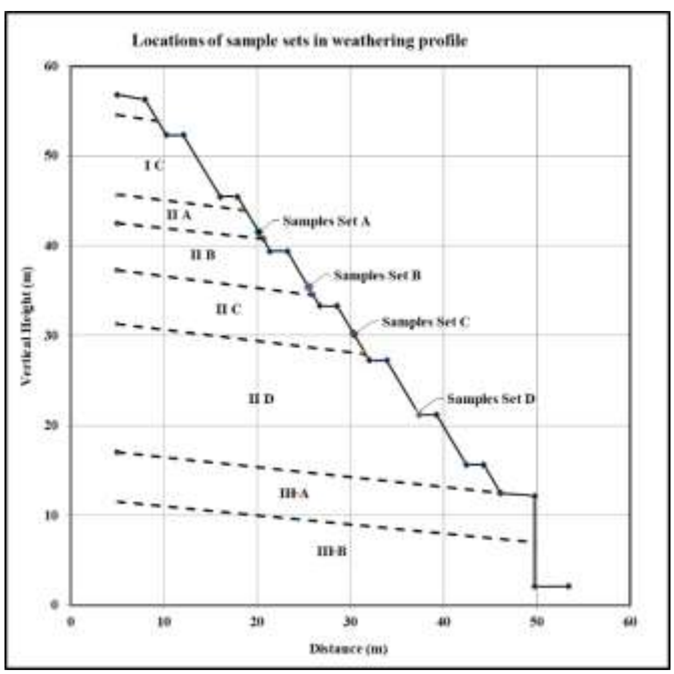

Figure 2: Locations of sample sets in weathering profile.

3.0 GEOLOGICAL SETTING OF INVESTIGATED WEATHERING PROFILE

The investigated weathering profile is developed over a porphyritic biotite granite that forms part of the eastern lobe of the Late Triassic (199 - 210 Ma) Kuala Lumpur Granite (Ng, 1992). The bedrock continues to outcrop to the west over a distance of about 10km, but to the east, is in contact with a sequence of schists, sedimentary and volcanic rocks, that occur as a roof pendant within the Main Range Granite (Haile *et al*., 1977).

The granitic bedrock exposed at the cut is strongly jointed and cut by a number of moderately to steeply dipping faults of variable strike. A number of epidote and quartz feldspar veins with tourmaline as well as aplite and leucocratic microgranite dykes are also seen within the bedrock. The grey bedrock is medium to coarse grained and usually porphyritic with large alkali feldspar phenocrysts (up to 4 cm in length). The essential minerals are quartz, alkali feldspar, plagioclase feldspar and biotite, whilst the accessory minerals include apatite, tourmaline and zircon. Quartz occurs as anhedral crystals, filling interstices in the groundmass and sometimes forms small phenocrysts. The alkali feldspars include microcline, orthoclase and perthite, and occur both as phenocrysts and as fine to medium grained crystals in the groundmass. The alkali feldspars sometimes contain quartz, biotite and plagioclase inclusions. The plagioclase feldspars, of albite to andesine composition, are usually found as euhedral to subhedral, fine to medium grained crystals in the groundmass and are often sericitized. The biotites occur as fine to medium grained, generally euhedral crystals and found both as disseminated grains and as aggregates in the bedrock. Close to the faults, hydrothermal alteration of the plagioclase feldspar and biotite grains has occurred.

4.0 MORPHOLOGICAL ZONATION OF WEATHERING PROFILE

Descriptions of the different morphological zones (and sub-zones) are summarized in Table 1 and schematically shown in Figure 3 (Raj, 1985). In situ development of the saprock (zone II) indicates alteration (weathering) of bedrock due to gradual lowering of an unconfined groundwater table which is now located at its' (zone II) bottom.

The pedological soil (zone I) is 9.4 m thick with the A and B soil horizons (solum) consisting of friable to firm, sandy clay, whilst the C horizon (saprolite) comprises stiff to very stiff, clayey sand with indistinct to distinct relict granitic textures (Table 1). The saprock (zone II) is 31.7 m thick and consists mainly of gravelly silty sands that indistinctly to distinctly preserve the minerals, textures and structures of the original granite; the degree of preservation increasing with depth. This Zone can be separated into four sub-zones; the top two (II A and II B) devoid of core-boulders, whilst the lower two, II C and II D, have some (<40% by area), or many (>70% by area), core-boulders, respectively (Table 1). The bedrock (zone III) is a continuous granite outcrop with weathering (marked by narrow to broad, strips of gravelly silty sand) along, and between, discontinuity planes (III A), or only along discontinuity planes (III B).

In terms of rock mass weathering grades as proposed by IAEG (1981) and GSL (1990), the pedological soil (zone I) would be classified as rock mass weathering grade VI and the bedrock zone (zone III) as rock mass weathering grade II. In view of the litho-relicts (core-boulders) present, sub-zones II D, and II C, constitute rock mass weathering grades III and IV respectively, whilst sub-zones II A and II B would be classified as weathering grade V (Figure 3).

Table 1 Field descriptions of morphological zones and sub-zones (Raj, 1985).

Sub-zone	Thick-ness (m)	Field Description
I A	0.6	Brownish yellow, sandy clay, porous, soft; friable dry; sub-angular blocky; many roots; boundary irregular, diffuse.
I B	1.0	Reddish yellow, firm, sandy clay; friable, dry; sub-angular blocky; some roots; boundary wavy, sharp.
I C	7.8	Yellowish red, stiff to very stiff, clayey sand with some reddish yellow mottles; friable, dry; sub-angular blocky; indistinct to distinct relict bedrock texture; a few distinct relict quartz veins; boundary irregular, sharp.
II A	4.5	Yellowish red, friable, gravelly, silty sand with red & white mottles; thin bands & wedges of yellowish red clayey sand; distinct relict bedrock texture & quartz veins; some indistinct relict joint planes; boundary, irregular, diffuse.
II B	6.0	White, friable, gravelly silty sand with bands of yellowish red, gravelly silty sand; distinct relict bedrock texture, quartz veins & joint planes; boundary, irregular, diffuse.
II C	7.3	Pinkish to yellowish red, friable, gravelly silty sand; distinct relict bedrock texture, quartz veins, joint & fault planes; some fresh core-boulders (20 - 40% by area); boundary, irregular, diffuse.
II D	13.9	Dominantly partly weathered to fresh, rounded core-boulders (>70% by area) surrounded by thin to broad bands of whitish, friable, gravelly silty sand with distinct relict bedrock textures, quartz veins, joint & fault planes; boundary, irregular, sharp.
III A	5.0	Continuous granite outcrop with effects of weathering (including alteration of feldspars & formation of gravelly silty sand) along & between joint & fault planes; boundary, broken, diffuse.
III B	>2.0	Continuous granite outcrop with effects of weathering along joint & fault planes only.

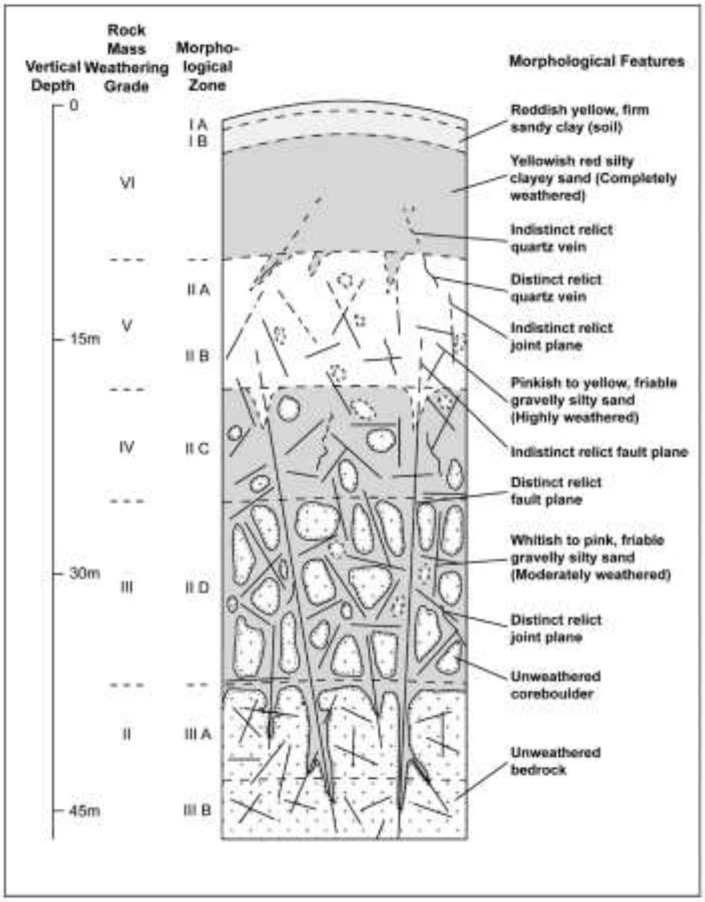

Figure 3: Schematic sketch of morphological features in the weathering profile.

5.0 RESULTS

5.1 Descriptions Of Sampled Earth Materials

The samples were collected at different depths in saprock (zone II) in sub-zones II A, II B, II C and II D (Figure 2) and thus retain the original granitic bedrock texture (Table 2). Minor variations in composition are seen; the clay fractions all characterized by the presence of kaolinite with illite also additionally present in Sets C and D. The coarse grained fractions of all samples consist of angular quartz grains, sericite flakes and altered (kaolinized) feldspar grains; fresh feldspar fragments also present in the Set D samples (Table 2).

Table 2 Descriptions of sampled earth materials.

Set Samples	Sub-zone	Vertical Depth	Description
Set A	II A	16.11 m	Yellowish red, friable, silty sand with distinct relict granitic texture. Very highly weathered granite. Coarse fraction of quartz grains and sericite flakes with a few kaolinized feldspar fragments. Clay fraction of kaolinite.
Set B	II B	20.86 m	Pinkish to yellowish, friable, gravelly silty sand with distinct relict granitic texture. Very highly weathered granite. Coarse fraction of quartz grains and sericite flakes with some kaolinized feldspar fragments. Clay fraction of kaolinite.
Set C	II C	31.29 m	Pinkish to grey, friable, gravelly silty sand with distinct relict granitic texture. Highly weathered granite. Coarse fraction of quartz grains and sericite flakes with many kaolinized feldspar fragments. Clay fraction of kaolinite with some illite.
Set D	II D	37.26 m	White to light grey, friable, gravelly silty sand with distinct relict granitic texture. Moderately weathered granite. Coarse fraction of quartz grains and sericite flakes with some kaolinized and fresh feldspar fragments. Clay fraction of kaolinite and illite.

5.2 Physical Properties Of Sampled Earth Materials

As the samples were collected at different depths in saprock (zone II), there are some differences in their physical properties (Table 3). Constant volume samples show their dry unit weights to range between 12.58 and 13.50 kN/m^3, whilst their dry densities are between 1,282 and 1,376 kg/m^3. Porosity shows limited variations with values of 47.0% to 50.7%, whilst the specific gravity of constituent mineral grains ranges from 2.596 to 2.626. Moisture contents are somewhat variable from 7.7% to 13.0%, whilst the degrees of saturation range from 19.5% to 38.1% (Table 3).

Table 3 Physical properties of sampled earth materials.

Set Samples	Dry Unit Weight (kN/m^3)	Dry Density (kg/m^3)	Specific Gravity Particle	Porosity (%)	Moisture Content (%)	Degree Saturation (%)
Set A	13.50	1,376	2.596	47.0	13.0	38.1
Set B	12.59	1,283	2.600	50.6	8.9	22.5
Set C	12.58	1,282	2.600	50.7	7.7	19.5
Set D	13.22	1,348	2.626	48.7	11.5	32.9

5.3 Soil Index Properties Of Sampled Earth Materials

Soil index properties show variations with sampling depth in view of differences in the extent of alteration of the original granite (Table 4). Gravel contents are variable and range from 5% to 17%, whilst sand contents are between 51% and 62%. Sand and gravel sized particles thus form some 66% to 72% of the samples. Silt contents are about similar in all samples, ranging from 21% to 24%, whilst clay contents are more variable and between 4% and 11%. Plastic limits show a limited variation with values between 36.0% and 42.5% (Table 4), though liquid limits could not be determined due to the large silt contents that prevented the use of the standard Casagrande grooving tool.

Table 4 Soil index properties of sampled earth materials.

Set Samples	Sub-zone	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Gravel & Sand (%)	Plastic Limit (%)
Set A	II A	5	61	23	11	66	38.6
Set B	II B	10	62	24	4	72	42.5
Set C	II C	17	51	23	9	68	41.7
Set D	II D	15	57	21	7	72	36.0

5.4 Stress-Strain Plots Of UU Triaxial Tests

Plots of deviator stress (σ1 - σ3) versus axial strain under different cell pressures for the individual specimens of all sample sets are generally similar, though there are some variations with texture and moisture content (Figures 4, Figure 5, Figure 6 and Figure 7). The plots for the individual specimens of sample sets A, C and D are closely similar; the plots rising steeply to a broad peak (between 10% and 20% of axial strain) and then gradually falling (Figure 4, Figure 6 and Figure 7). These plots are quite similar to those of consolidated drained triaxial tests on loose sands (and normally consolidated clays) where the curves gradually rise to a peak value and then become horizontal (Lambe and Whitman, 1973).

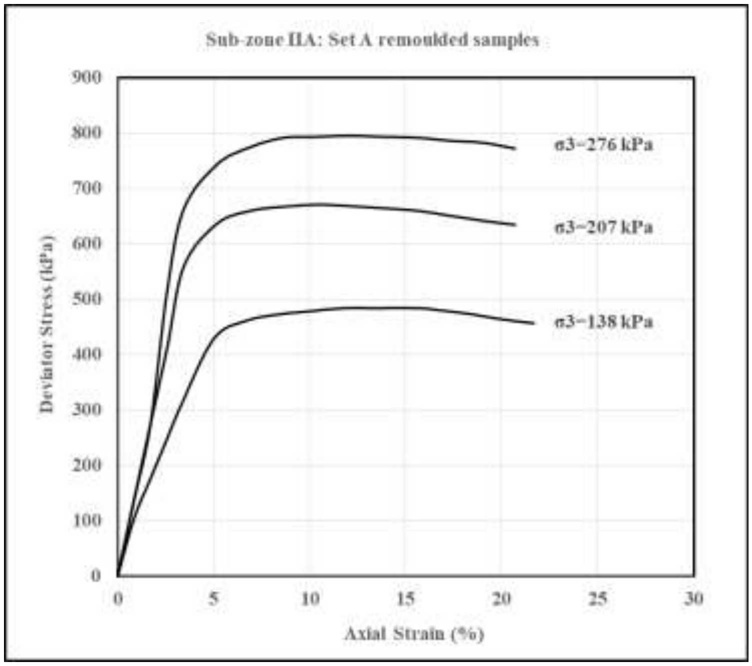

Figure 4 Stress-strain plots of UU triaxial tests on Set A remolded samples (sub-zone II A).

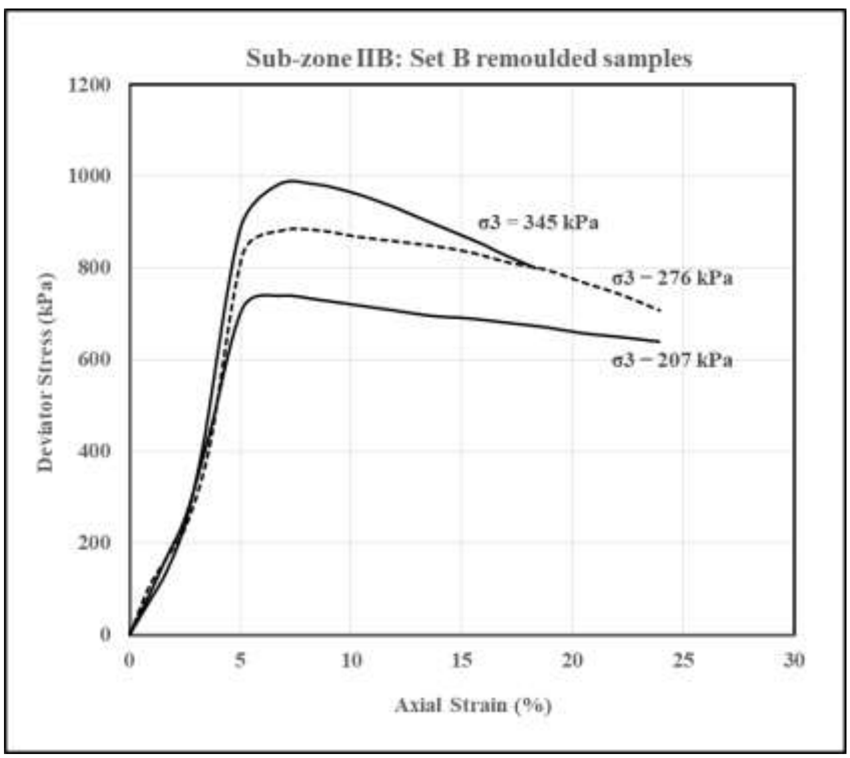

Figure 5 Stress-strain plots of UU triaxial tests on Set B remolded samples (sub-zone II B).

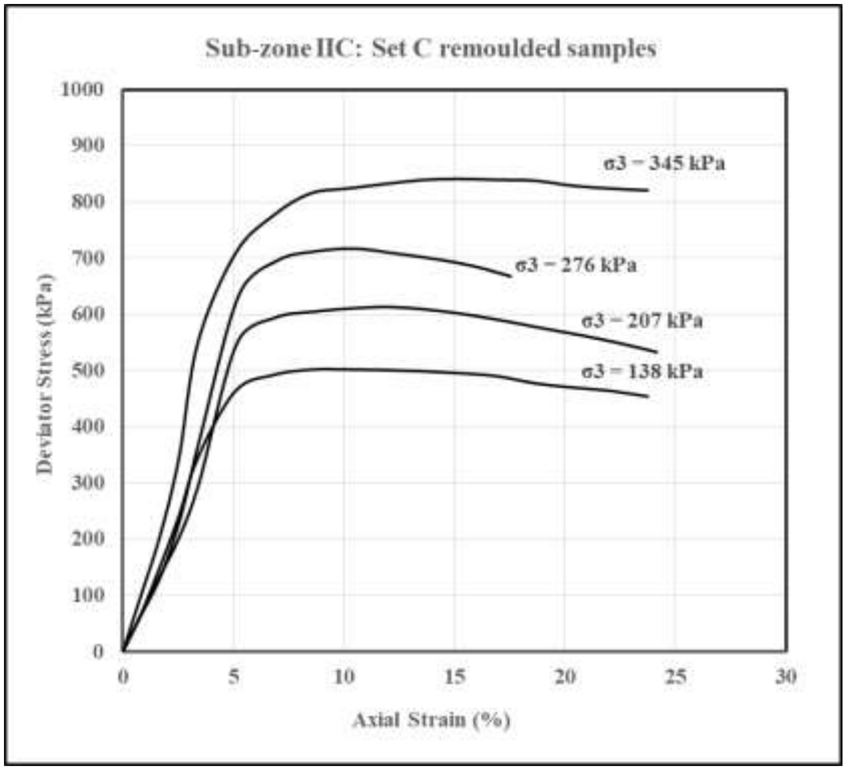

Figure 6 Stress-strain plots of UU triaxial tests on Set C remolded samples (sub-zone II C).

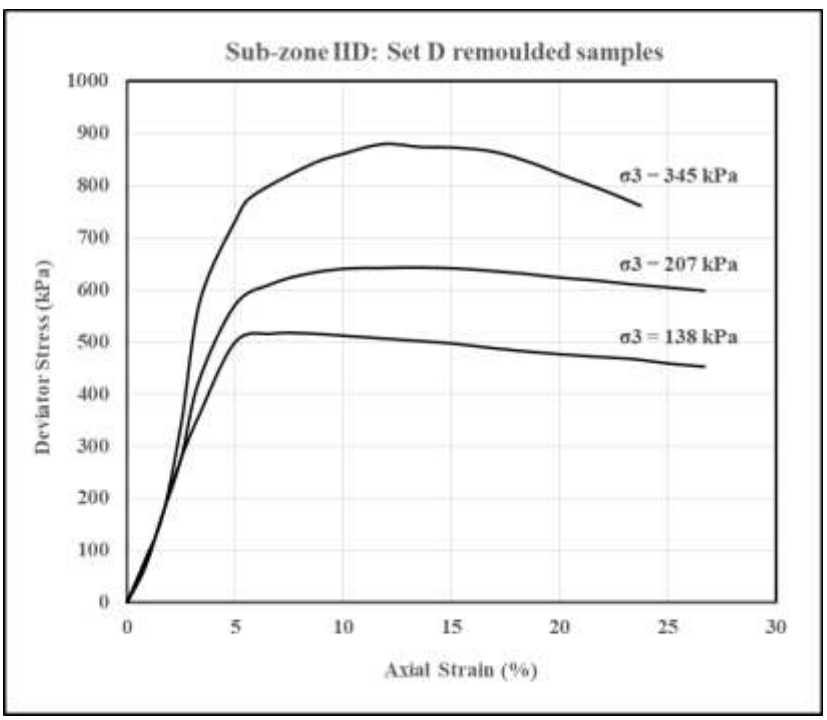

Figure 7 Stress-strain plots of UU triaxial tests on Set D remolded samples (sub-zone II D).

Plots of deviator stress versus axial strain of sample set B, however, rise steeply to a narrow peak (between 6% and 9% strain) and then fall sharply (Figure 5). These plots are more akin to those of consolidated drained triaxial tests on dense sands (and over-consolidated clays) where the curves rise to a peak value and then drop to a horizontal position (Lambe and Whitman, 1973). Interestingly enough, sample set B has the lowest clay, but largest sand and gravel, contents (Table 4).

Results of the UU tests in terms of the cell pressure (σ3) and deviator stress (σ1 - σ3) at peak axial strain are listed in Table 5.

Table 5 Results of unconsolidated, undrained triaxial tests on remolded samples.

Set	Sample No.	Sub-zone (RMWG)	Cell Pressure (kPa)	Peak Axial Strain (%)	Peak Deviator Stress (kPa)
A	A1	II A (V)	138	13.3	483.5
A	A2	II A (V)	207	10.3	670.5
A	A3	II A (V)	276	12.1	795.0
B	B1	II B (V)	207	6.8	739.8
B	B2	II B (V)	276	8.5	883.2
B	B3	II B (V)	345	8.3	983.6
C	C1	II C (IV)	138	10.2	502.2
C	C2	II C (IV)	207	12.1	613.2
C	C3	II C (IV)	276	10.5	717.1
C	C4	II C (IV)	345	15.3	841.1
D	D1	II D (III)	138	8.3	516.4
D	D2	II D (III)	207	13.3	642.5
D	D3	II D (III)	345	11.9	879.5

5.5 Undrained Shear Strength Parameters

Plots of the values of pf = [(σ1 + σ3)/2] and qf = [(σ1 - σ3)/2] of individual specimens and the drawing of Kf-lines (after Lambe and Whitman, 1973) allowed for calculation of the undrained shear strength parameters. An example of the calculation procedure involved is shown in Table 6.

Table 6 Example of calculating strength parameters from p_f versus q_f plots - Set A samples from sub-zone IIA.

Formula for K_f-*line* from regression analysis	Parameters
y = 0.5322x + 41.885	R^2 = 0.9971
Apparent cohesion = Intercept = c	c = 41.9 kPa
Tan ά = 0.5322	sin ϕ = tan ά
Apparent angle of friction = ϕ	ϕ = 32.15°

The results show the undrained shear strength of saprock to be characterized by values of both apparent cohesion (c) and angle of internal friction (ϕ) (Table 7). Apparent cohesions are quite variable, with the sample sets from sub-zones II A, II B, II C and II D, being characterized by values of 41.9 kPa, 100.3 kPa, 76.1 kPa, and 73.9 kPa, respectively (Table 6). Apparent friction angles, however, are less variable with the sample sets from sub-zones II A, II B, II C and II D, being characterized by values of 32.2°, 28.1o, 26.6° and 27.8°, respectively (Table 7). When the values of pf = [(σ1 + σ3)/2] and qf = [(σ1 - σ3)/2] for all sample sets are plotted, an overall apparent cohesion of 54.6 kPa, and friction angle of 30.5° is calculated for the saprock (Table 7).

Table 7 Undrained shear strength parameters of saprock.

Set Samples	Sub-zone (Rock Mass Weathering Grade)	Vertical Depth (m)	Apparent Cohesion (c) (kPa)	Apparent Friction Angle (ϕ°)
A	II A (V)	16.11	41.9	32.2°
B	II B (V)	20.86	100.3	28.1°
C	II C (IV)	31.29	76.1	26.6°
D	II D (III)	37.26	73.9	27.8°
A. B. C & D	Saprock	Zone II	54.6	30.5°

6.0 DISCUSSION

It has been earlier noted that there is very little published data on the undrained shear strength parameters of earth materials in weathering profiles over granitic bedrock in Peninsular Malaysia. The following discussion thus considers the many factors that influence the undrained shear strength parameters of saprock (earth materials in morphological zone II) at the investigated weathering profile.

6.1 Published Values Of Undrained Shear Strength Parameters

The apparent cohesions of 41.9 to 100.3 kPa determined in the present study correlate well with the values of 61.8 to 117.0 kPa determined in UU tests on a residual soil over granite treated as a sand-silt-clay composite mixture (Ting and Ooi, 1976). The apparent friction angles of between 26.6° and 32.2° of the present study, however, are much larger than those between 1° and 9.5° reported in the earlier study (Ting and Ooi, 1976). Details on the samples of the earlier study are not available, but it is considered likely that their clay contents are much greater than those of the present study (Tables 7 and 8).

The apparent cohesions of the present study also correlate well with those between 27 and 87 kPa determined from UU triaxial tests on samples at a depth of 15 m in a residual soil over granite (Todo and Pauzi, 1989). The apparent friction angles of less than 11° reported in this earlier study are, however, much lower than those of the present study (Tables 7 and 8). Details on the samples of the earlier study are not available, but it is considered likely that the lower values of friction angle are due to a greater clay content.

Apparent friction angles of 31° to 35° reported from UU triaxial tests on a remoulded gravelly silt (Salih and Kassim, 2012) correlate well with those determined in the present study (Tables 7 and 8). The apparent cohesion values of between 10 and 13 kPa determined in this earlier study, however, are much lower than those of the present study. Variations in texture and mineral composition are considered responsible for the differences as samples of the earlier study were collected at a depth of 1.5 to 2.5 m in the pedological soil profile (morphological zone I).

Table 8: Shear strength parameters from UU triaxial tests on residual soils over granite.

No	Soil type	Rock Mass Weathering Grade (Depth)	Apparent Cohesion (kPa)	Friction Angle	Reference
1	Sand-silt-clay mixture	Not known	61.8 - 117	1° - 9.5°	Ting & Ooi (1976)
2	Granitic soil	V (15 m)	27.0 - 87.0	<11°	Todo & Fauzi (1989)
3	Gravelly silt (Topsoil)	VI (1.5-2.65 m)	10 - 13	31° - 35°	Salih & Kassim (2012)
4	Granitic soil	Not known	15 - 44	21° - 32°	Salih (2012)

6.2 Apparent Friction Angle Of Saprock (Zone II) Samples

The undrained strength parameters of all sample sets are characterized by moderate values of the apparent friction angle, ranging from 26.6° to 32.3°, with an average value of 30.5° (Table 7). These friction angles, however, show little or no correlation with most physical and soil index properties of the saprock including density, porosity. silt and clay contents; linear regression analyses yielding low R-squared values (<0.5). The best correlation is an increase of friction angle with an increase in sand contents; the R-squared value being 0.4386 (Figure 8). This increase is expected for in situ alteration of the granitic bedrock results in angular, sand sized, quartz grains whose increased contents will cause greater inter-locking and resistance to displacement.

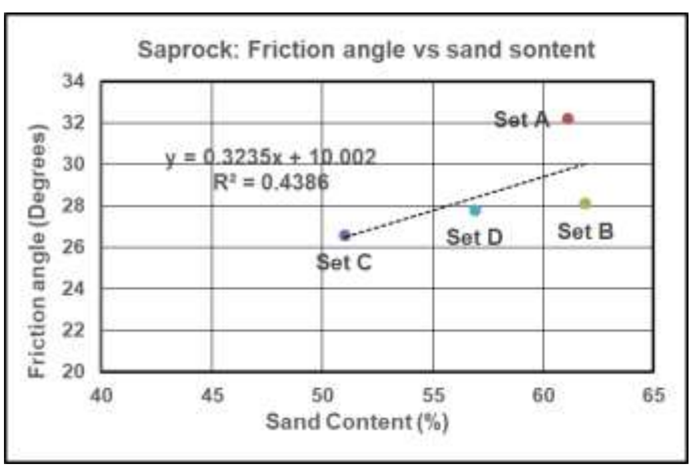

Figure 8: Apparent friction angle versus sand content of saprock (zone II) samples.

6.3 Apparent Cohesion Of Saprock (Zone II) Samples

The undrained strength parameters of all sample sets are characterized by large values of apparent cohesion ranging from 41.9 to 100.3 kPa, with an average value of 54.6 kPa (Table 7). Such apparent cohesions from Mohr-Coulomb failure envelopes of triaxial tests on 'residual soils' over granitic bedrock have been considered to reflect the existence of bonds between particles (Tan and Gue, 2001). Several causes have been proposed for the bonds as cementation through deposition of carbonates, hydroxides and organic matter, pressure solution and re-precipitation of cementing agents and the growth of bonds during chemical alteration of minerals (Tan and Gue, 2001; Vaughn, 1988). Such bonds, however, are not expected to be present in specimens of the present study as they involve remolded specimens (i.e. specimens recompacted from disaggregated tube samples).

Regression analyses furthermore, show little correlation between the values of apparent cohesion and most physical and soil index properties of the saprock as density, porosity, sand and silt contents; the analyses yielding low R-squared values (<0.4). Apparent cohesions, however, decrease with increasing degrees of saturation, though the R-squared value (0.6012) is not large (Figure 9). This decrease in apparent cohesion with increasing saturation is not unexpected for soil-moisture retention curves show saprock samples to experience increasing suction (or negative pore water pressures) with decreasing moisture contents (Raj, 2010).

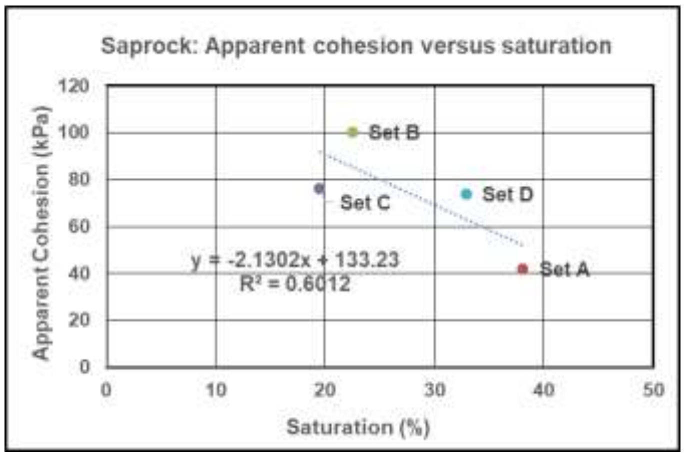

Figure 9 Apparent Cohesion Versus Degree Of Saturation Of Saprock (Zone II) Samples.

Apparent cohesions also distinctly decrease with increasing clay contents with a fairly large R-squared value (0.8701) (Figure 10). This decrease in apparent cohesion with an increase in clay contents is considered to result from the increase of specific surface areas (SSA). Increased specific surface areas are expected to allow for increased volumes of water adsorption and thus increased degrees of saturation.

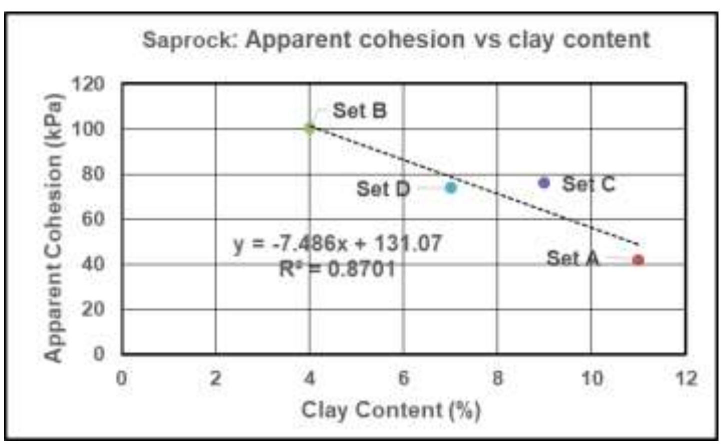

Figure 10 Apparent cohesion versus clay content of saprock (zone II) samples.

7.0 CONCLUSIONS

The exposed weathering profile was differentiated into three broad zones; an upper, 9.4 m thick, pedological soil (zone I), an intermediate, 31.7 m thick, saprock (zone II) and the bottom bedrock (zone II). The saprock (zone II) comprises gravelly silty sands that indistinctly to distinctly preserve the minerals, textures and structures of the original granite and can be separated into sub-zones II A, II B, II C, and II D, based on differences in preservation of relict structures and content of litho-relicts (core-boulders).

To characterize the undrained strength of saprock, samples were collected from sub-zones II A, II B, II C and II D and their physical and soil index properties determined before unconsolidated undrained triaxial tests were carried out on remolded samples. Three to four individual samples from each sub-zone were compressed under confining pressures of 138 kPa, 207 kPa, 276 kPa and/or 345 kPa. Plots of pf = [(σ1 + σ3)/2] versus qf = [(σ1 - σ3)/2] were then used to calculate apparent cohesions of 41.9 kPa, 100.3 kPa, 76.1 kPa and 73.9 kPa, and friction angles of 32.2^o, 28.1^o, 26.6^o and 27.8^o, for the samples from sub-zones II A, II B, II C, and II D, respectively.

Regression analyses show apparent cohesions to decrease with increasing clay contents and degrees of saturation; features indicating the influence of negative pore water (or suction) pressures. Regression analyses also show the apparent friction angle to increase with increasing sand contents; a feature attributed to greater inter-locking and resistance to displacement of these particles.

It is concluded that the undrained shear strength parameters of saprock are characterized by an average apparent cohesion of 54.6 kPa, and average friction angle of 30.5^o; the parameters influenced by the particular the degree of saturation as well as clay and sand contents.

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