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Saturated hydraulic conductivity (Ks) of earth materials in the weathering profile over quartz-mica schists of the Seremban area, Negeri Sembilan

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Abstract: The weathering profile at the slope cut at Km 67.9 of the Kuala Lumpur – Seremban Highway, can be differentiated into two broad zones; an upper pedological soil (Zone I) and a lower saprock (Zone II). The pedological soil (some 4.8 m thick) comprises firm to stiff, clayey sands and silts with many gravel-sized, lateritic concretions and vein quartz clasts and can be subdivided into the solum (IA and IB soil horizons) and saprolite (IC horizon). The aprock is more than 16.2 m thick and consists of *in situ*, moderately to highly weathered quartz-mica schists marked by steeply dipping to vertical bands of variable thickness of firm to hard, pink to light grey and white silts and sandy silts. Foliation and fracture planes as well as quartz veins and pods are distinctly preserved as relict structures in the saprock. Laboratory constant head permeability tests show clayey silts from sub-zone IIB with distinct relict foliation planes to have saturated hydraulic conductivities (Ks) of 0.0611, and 0.0838, cm/hr with flow perpendicular, and about perpendicular, to the foliation. Sandy silt from sub-zone IIA with indistinct relict foliation planes has a saturated hydraulic conductivity of 0.2977 cm/hr, whilst silts from sub-zone IIC with distinct relict foliation planes have conductivities of 0.7365, and 0.3864, cm/hr with flow parallel, and steeply inclined, to foliation, respectively. It is concluded that the saturated hydraulic conductivity (Ks) of earth materials within the weathering profile over quartz-mica schists is dependent upon the orientation of the inherent relict foliation planes.

Keywords: Quartz-mica schists weathering profile, saturated hydraulic conductivity

INTRODUCTION

The movement of water through earth materials is governed by the experimentally derived Darcy's Law [Q = KiA] which states that the discharge of water (Q) through a unit area of porous medium is directly proportional to the hydraulic gradient (i) normal to that area (A); K being the proportionality constant (Sharp, 2007). In Geology, the proportionality constant (K) has been known as the coefficient of permeability, though nowadays, it is referred to as the hydraulic conductivity. Hydraulic conductivity is defined as the rate of flow of water through a cross-sectional area under a unit hydraulic gradient at the prevailing temperature (Bates & Jackson, 1980).

The property or capacity of a porous rock, sediment or soil to transmit a fluid without impairment of the medium is termed permeability and can be considered to be a measure of the relative ease of flow under unequal pressure; the SI unit of measurement being m^2 (for saturated flow) (Bates & Jackson, 1980). The term intrinsic permeability, refers to the permeability of earth materials independent of fluid properties and is related to the hydraulic conductivity (K) by $K = k\rho g/\mu$, where k is the intrinsic permeability, ρ is the density of the liquid, g the acceleration due to gravity and μ is the dynamic viscosity of the liquid (Lewis *et al*., 2006).

In Soil Science, intrinsic permeability (k) is considered to be a quantitative property of porous material that is controlled solely by pore geometry (USDA, 2018). Saturated hydraulic conductivity (Ks) furthermore, is considered to be a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient and can be described as the ease with which pores of a saturated soil permit water movement (USDA, 2018). Saturated hydraulic conductivity is affected by both soil and fluid properties and depends on the soil pore geometry as well as the fluid viscosity and density. In contrast to hydraulic conductivity, intrinsic permeability is independent of fluid viscosity and density. In some cases in Soil Science, however, permeability (k) has been used as a synonym for saturated hydraulic conductivity (Ks), even though some other quantity was originally used to convey permeability (USDA, 2018). This misrepresentation led to some confusion and misapplication and is considered to be an important reason for use of the term saturated hydraulic conductivity (Ks) nowadays (USDA, 2018).

There is limited published data on the saturated hydraulic conductivity (Ks) of earth materials in Malaysia where deep weathering profiles are found as a result of prolonged and pervasive weathering throughout most of the

Cenozoic Era (Raj, 2009). The earliest published data is from the Cameron Highlands Hydro-Electric Scheme where water absorption tests in boreholes in fresh to slightly weathered granite (Grades I and II) at depth yielded coefficients of permeability less than 5 Lugeons (<0.18 cm/hr), whilst those at shallow depths had coefficients between 10 and 40 Lugeons (0.36 to 1.44 cm/hr) (Dickinson & Gerrard, 1963). Field and laboratory tests furthermore, yielded coefficients of permeability between 0.36 and 3.60 cm/hr for moderately weathered granite (Grade III), between 1.62 and 32.40 cm/hr for highly weathered granite (Grades IV and V), and between 1.01 and 9.36 cm/hr for completely weathered granite (Grade VI). Water absorption tests in boreholes in fresh to slightly weathered meta-sedimentary bedrock in the Cameron Highlands Hydro-Electric Scheme yielded coefficients of permeability between 0.11 and 0.90 cm/hr and those in friable weathered schist, coefficients between 0.32 and 4.32 cm/hr (Dickinson & Gerrard, 1963).

Water movement using dyes in soils at the Bukit Tarek Experimental Watershed found that the saturated hydraulic conductivity (Ks) decreased with depth (Noguchi *et al*., 1997). Measured values of hydraulic conductivity ranged from 16.88 to 146.52 cm/hr and were found to be much higher than those of other tropical soils. The study concluded that subsurface water flow may play an important role during stormflow generation, rather than saturation overland flow.

A study has been carried out to evaluate the hydraulic conductivity of granite, basalt, schist, and shale, saprolites from 16 locations in Peninsular Malaysia (Hamdan *et al*., 2009). The study found that granite saprolite had the highest values of saturated hydraulic conductivity (Ks), and *in situ* field infiltration rate, at 6.5, and 4.0, cm/hr, respectively, whilst the basalt saprolite had the lowest values at 0.10, and 0.03, cm/hr, respectively. The schist, and shale saprolites, furthermore had intermediate values of 1.10, and 0.25, cm/hr, for the saturated hydraulic conductivity, and 0.60, and 0.06 cm/hr, respectively, for the field infiltration rate. Clay and sand contents as well as porosity, pore shape and pore size were found to influence the hydraulic conductivity. The study concluded that shale and basalt saprolites would be suitable for use in *in situ* wastewater treatment in view of their slow to very slow infiltration rates (Hamdan *et al*., 2009).

In the course of a study on the characterization of weathering profiles in Peninsular Malaysia, a profile developed over quartz-mica schists that outcrop in the Seremban area of Negeri Sembilan State was investigated (Raj, 1983). In this paper, the results of the laboratory determinations of the saturated hydraulic conductivity (Ks) of earth materials at various depths within the weathering profile are presented.

GEOLOGICAL SETTING OF WEATHERING PROFILE

The investigated weathering profile is exposed at the slope cut on the north side of the Kuala Lumpur – Seremban Highway at Km 67.9. The Highway here cuts across a low hill and trends in a general west to east direction across an undulating terrain of low ridges and flat-bottomed valleys developed over quartz-mica schists (Figure 1). The schists, which have an abundance of quartz lenses and pods, are strongly folded and have been correlated with the Lower Palaeozoic Dinding Schist of the Kuala Lumpur area (Khalid, 1972).

The cut is of an approximately symmetrical shape with a length of some 150 m along its base and a maximum vertical height of 20 m at its center. The cut, which has an overall angle of 40°, is benched with the benches of some 2.75 m vertical height and face angles of 50°, separated by horizontal berms of variable width. The lowest bench, however, is some 6 m high with a face angle of 80°.

At the cut is exposed a weathering profile developed over an original bedrock mass comprising light grey to white, quartz-muscovite schists inter-layered with thin bands and lenses of dark grey, graphitic-quartz-muscovite schist (Raj, 1993). The indistinctly- to distinctly-preserved relict foliation, though variable, mainly strikes north-south with very steep to vertical dips. Several indistinct to distinct, relict joint-and a few relict fault-planes of variable orientation are also seen.

In thin-sections, the less weathered quartz-muscovite schist bands are seen to consist of thin layers (about 0.5 mm thick) of fine-grained quartz crystals in parallel alignment with thicker layers (up to 5 mm thick) of aligned sericite, muscovite and clay minerals. The less weathered graphitic quartz-muscovite schist bands also show a similar appearance, except for the presence of graphite in the thick layers. In the thin-sections, secondary iron oxide and hydroxide stains and grains are also seen, whilst thin quartz veins and fissures are sometimes seen perpendicular to the foliation.

METHODOLOGY

Field mapping was first carried out to visually differentiate weathering zones within the exposed profile, i.e. zones of earth materials with similar morphological features as color, texture, organic matter content, mineral concentrations, biological activity and the like (FAO, 2006). Details of the morphological features present in the different weathering zones and sub-zones is summarized in Table 1 and schematically shown in Figure 2. This descriptive approach to characterizing the weathering profile was adopted in view of the total absence of fresh schist bedrock in boreholes and outcrops in the general area; the absence preventing definition of the stages of weathering of bedrock. It has also been pointed out that standard weathering classifications of rock mass (IAEG. 1981) require considerable modification when applied to sedimentary and meta-sedimentary bedrock in tropical areas in view of their continuous weathering to form residual soils (Komoo & Morgana, 1988).

Brass tubes of 4.0 cm length and 7.6 cm internal diameter were used for the collection of two sets of

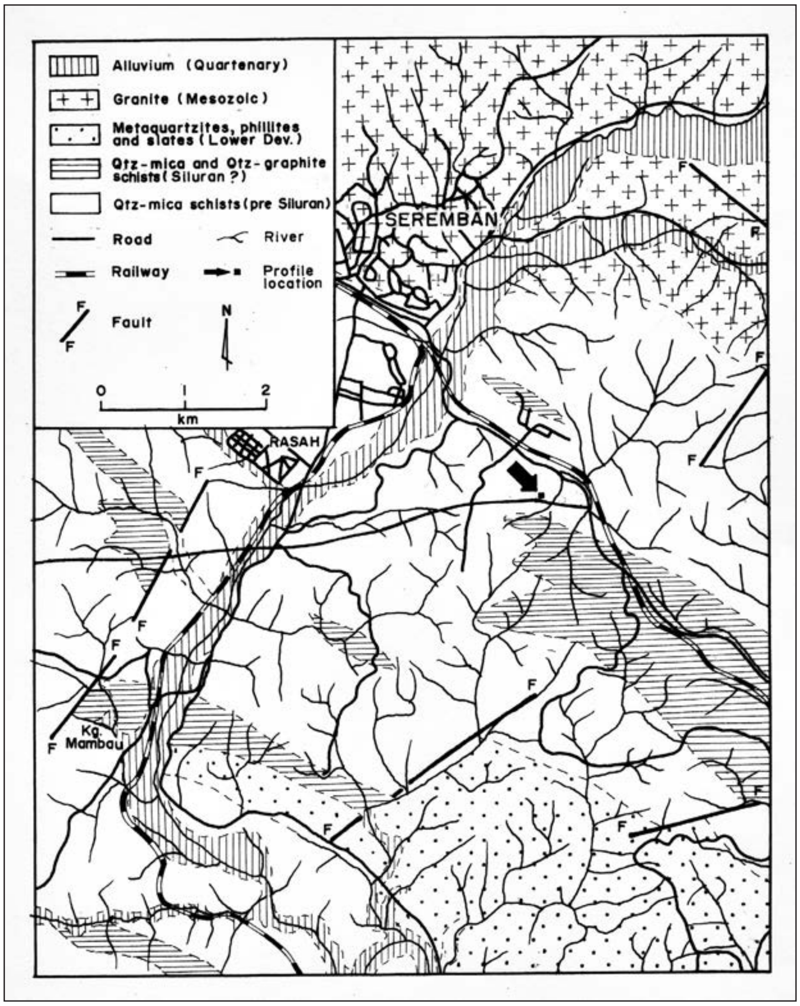

Figure 1: Geological sketch map of the Seremban area (after Khalid, 1972).

Table 1: Morphological features of weathering zones and sub-zones.

Thickness	Sub-Zone	Morphological Features
0.4 m	IA	Yellowish red, firm clay with some roots and burrows.
1.9 m	IB	Red, firm clayey sand with abundant gravel sized lateritic concretions. A few lateritized corestones and vein quartz clasts. Few roots.
1.3 m	IC_1	Reddish yellow, stiff, clayey sand with yellow mottles. Some gravel sized vein quartz clasts and lateritized corestones.
1.2 m	IC_2	Reddish yellow, firm clayey silt with yellow mottles (completely weathered schist). Many gravel sized lateritized corestones and vein quartz clasts. Distinct relict quartz veins and pods. Indistinct foliation.
2.2 m	IIA	Thick bands and wedges of reddish yellow, firm clayey silt with indistinct relict foliation (completely weathered schist) alternating with thin bands of pink to grey, stiff silt with distinct relict foliation (highly weathered schist). Distinct relict quartz veins. Indistinct to distinct relict fracture planes.
7.7 m	IIB	Thick bands of pink to grey, stiff silt with distinct relict foliation (highly weathered schist) alternating with thin bands and wedges of reddish yellow, firm clayey silt with indistinct relict foliation (completely weathered schist). Distinct relict fracture planes, quartz veins and pods.
> 6.3 m	IIC	Thick bands of white to light grey, hard silt (moderately weathered schist) alternating with thin bands and wedges of pink to grey, stiff, silt (highly weathered schist). Distinct relict foliation and fracture planes, quartz veins and pods.

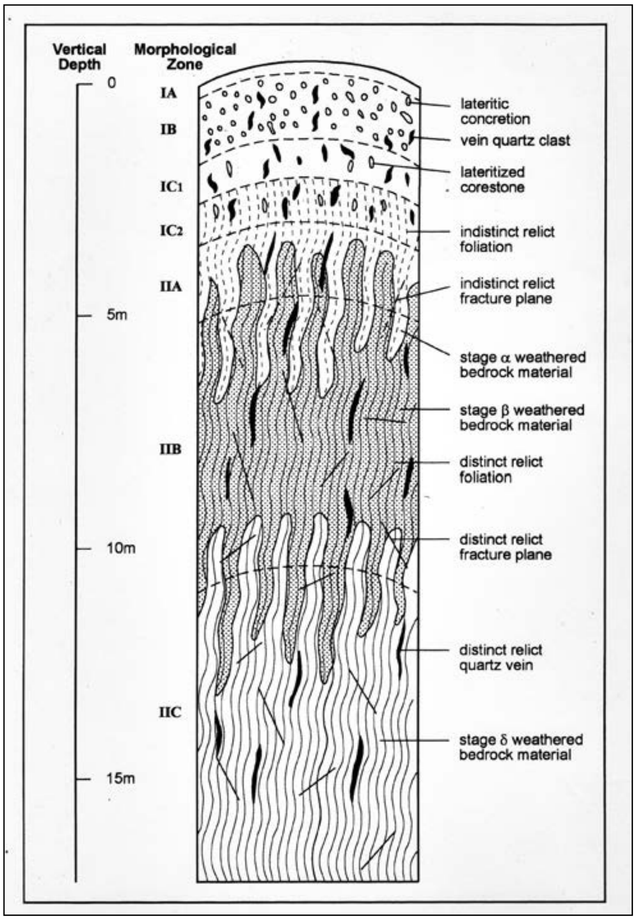

Figure 2: Schematic sketch of morphological features in the study site's weathering profile.

undisturbed, constant volume samples at four different depths within the weathering profile. The tubes had a constant wall thickness of 0.3 cm, except towards one end where the lower 1.5 cm tapered to a wall thickness of 0.15 cm to provide a cutting edge. Prior to sampling, the tubes were externally greased to facilitate entry into the soil while the surface materials at the site were cleared to a depth of 0.5 m to minimize surface influences.

Moisture contents, unit weights and densities of one set of the constant volume samples were determined before the specific gravity of the constituent mineral grains was measured using a pycnometer (GBRRL, 1959). Porosities were then calculated before the plastic limits of the fine fractions (<0.425 mm size) were determined according to the standard method (GBRRL, 1959). Particle size distributions of the samples were determined by employing the sieving and sedimentation methods for the coarse (>0.0625 mm diameter), and fine, fractions respectively (GBRRL, 1959). The main minerals present in the sand and coarse silt fractions were identified with the aid of a binocular microscope, whilst X-ray diffraction analyses were carried out to identify the clay minerals present (Raj, 1993). It is to be noted that the definitions of size limits for particles follows that of Wentworth (1922) where gravel refers to particles with diameters between 2 and 64 mm, sand to particles with diameters between 0.625 and 2.00 mm, silt to particles with diameters between 0.0039 and 0.0625 mm and clay to particles less than 0.0039 mm in diameter.

Saturated hydraulic conductivity (Ks) was measured by covering both ends of the constant volume sampling tube (from the second set) with filter paper and wire gauze screens before sealing them between araldite end caps. The araldite caps with the enclosed sampling ring were then placed between two brass plates and held in place by three bolts and nuts. The outlet from the upper araldite cap was attached to a vacuum pump whilst the outlet from the lower cap was placed in a large water-filled beaker with its top water level on par with the top of the sample ring. The vacuum pump was then started and water allowed to flow through the sample until it emerged at the outlet of the upper araldite cap. The vacuum pump was stopped and the water-filled beaker raised to a known height. The discharge of water from the outlet of the top araldite cap was then measured over a period of up to 12 hours until a constant rate of discharge was recorded. From the known cross-sectional area (A) and length (L) of the sample, as well as the constant head (H) and rate of discharge (Q/t), the saturated hydraulic conductivity (Ks) was calculated. A schematic sketch of the set-up for the constant head permeability test is shown in Figure 3.

RESULTS

Description of collected samples

Earth materials in the weathering profiles of humid tropical areas as Peninsular Malaysia indistinctly to distinctly preserve (as relict features) the minerals, textures and structures of the original bedrock material and mass (Raj, 2009). Descriptions therefore, need to be provided of the earth materials from weathering profiles that are investigated in the field or tested in the laboratory. As shown in Table 2, the earth materials of the present study show distinct variations in preservation of the original bedrock textures and structures for they were collected at different depths within the profile. Less weathered bedrock with distinct relict foliation planes is represented by the samples collected at depth in sub-zones IIB and IIC, whilst more weathered bedrock with indistinct to distinct relict foliation planes is represented by the sample from sub-zone IIA (Table 2).

There can also be seen some variation in mineral composition of the samples with depth; the less weathered bedrock of sub-zones IIB and IIC having their sand and coarse silt contents consisting predominantly of sericite flakes with some quartz and a few secondary iron oxide grains. The sand and coarse silt fractions of the more weathered bedrock in sub-zone IIA, however, comprise mainly quartz grains and sericite flakes with many secondary iron oxide grains. Clay minerals are also variable within

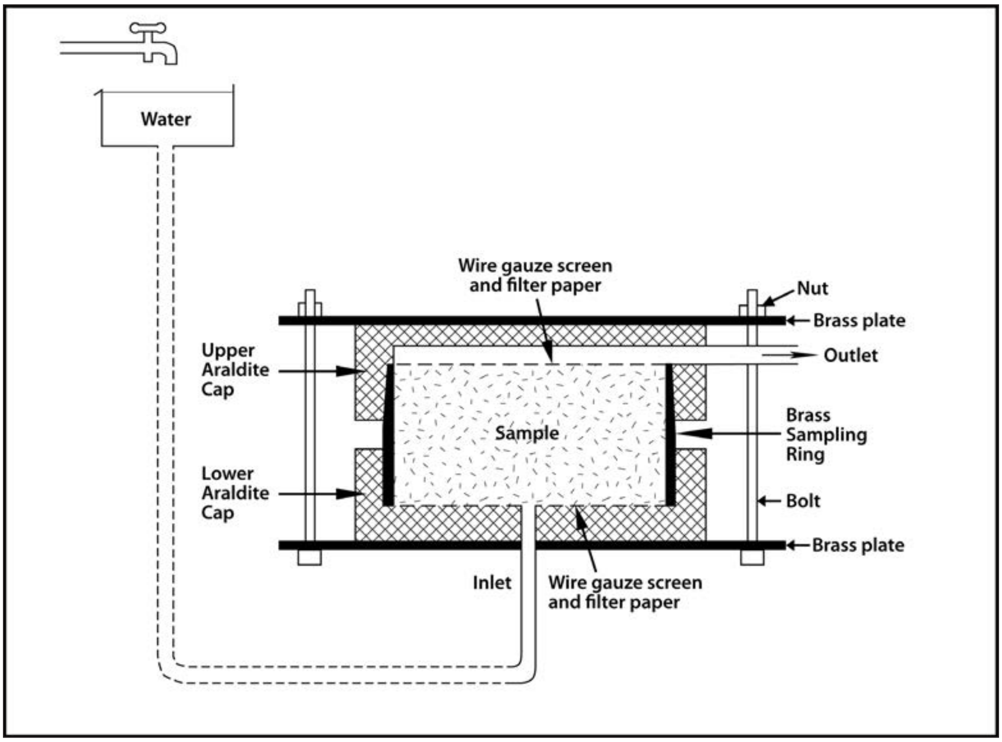

Figure 3: Schematic sketch of set-up for constant head permeability test.

Table 2: Description of samples collected for determination of the saturated hydraulic conductivity (Ks).

Sample No.	Vertical Depth (m)	Sub-zone	Description
1	6.07	IIA (Saprock)	Reddish yellow, sandy silt with indistinct relict foliation. Very highly weathered schist. Coarse fraction of sericite flakes with some quartz and secondary iron oxide grains. Clay fraction of kaolinite and illite.
2	7.47	IIB (Saprock)	Pinkish to grey, firm silt with distinct relict foliation. Highly weathered schist. Coarse fraction of sericite flakes with some quartz and secondary iron oxide grains. Clay fraction of illite and kaolinite.
3	10.74	IIB (Saprock)	Grey to whitish, stiff silt with distinct relict foliation. Highly weathered schist. Coarse fraction of sericite flakes with some quartz and secondary iron oxide grains. Clay fraction of illite and some kaolinite.
4a	15.05	IIC (Saprock)	White to grey, stiff to hard silt with distinct relict foliation. Moderately weathered schist. Coarse fraction of sericite flakes with some quartz and secondary iron oxide grains. Clay fraction of illite.
4b	15.05	IIC (Saprock)	White to grey, stiff to hard silt with distinct relict foliation. Moderately weathered schist. Coarse fraction of sericite flakes with some quartz and secondary iron oxide grains. Clay fraction of illite.

the profile; illite being the predominant mineral in sub-zone IIC, whilst both illite and kaolinite are found in the IIB and IIA sub-zones (Raj, 1993).

Physical properties of collected samples

Physical properties of the samples also show variations with depth; the dry unit weight decreasing up the profile from 18.19 kN/m^3 in sub-zone IIC through 17.79 and 17.76 kN/m^3 in sub-zone IIB to 17.36 kN/m^3 in sub-zone IIA (Table 3). The dry density also shows a corresponding variation with depth (Table 3). Field moisture contents show very limited variation with values of between 6.1 and 7.9% (Table 3).

The specific gravity of constituent mineral grains does not vary within the profile with a value of 2.70 for all samples (Table 4). This absence of variation is to be expected given the fairly similar composition of the minerals present. The porosity of the samples increases up the profile with the sub-zone IIC samples having the minimum value of 31%, whilst the samples from sub-zones IIB, and IIA, have values of 33%, and 34%, respectively.

Increasing effects of weathering processes up the profile are thus marked by a decrease in dry unit weight (and dry density), but also by an increase in porosity.

Index properties of collected samples

Grain size distributions are distinctly variable within the profile, especially in terms of the silt and clay contents. Silt contents show a distinct decrease up the profile; the sub-zone IIC samples having contents of 90%, the sub-zone IIB samples contents of 81% and 65%, and the sub-zone IIA sample having a content of 52% (Table 4). As the original bedrock is composed primarily of silt sized mica flakes, the decreasing silt contents up the profile point to the increasing effects of weathering processes.

Clay contents show a general increase up the profile; the sub-zone IIC samples having very low contents (10%) and those from sub-zone IIB having moderate contents (18% and 23%). A rather low clay content (11%) is seen in the sub-zone IIA sample, though this is likely due to the abundant sand-sized particles present (Table 4).

Sand contents within the profile are somewhat variable in view of the many inherent quartz veins and pods found as indistinct to distinct relict structures. Sand contents are absent in the sub-zone IIC samples and are of very low contents (1% and 12%) in the sub-zone IIB samples. Sand contents are unexpectedly high in the sub-zone IIA sample, though this is due to the sample having been collected close to some relict quartz veins and pods (Table 4).

Table 3: Physical properties of samples collected for determination of the saturated hydraulic conductivity (Ks).

Sample No.	Dry Unit Weight (kN/m^3)	Dry Density (kg/m^3)	Moisture Content (%)	Mineral Grain SG	Porosity (%)
1	17.36	1,770	6.3	2.70	34
2	17.76	1,810	6.1	2.70	33
3	17.79	1,814	7.9	2.70	33
4a	18.19	1,855	7.5	2.70	31
4b	18.19	1,855	7.5	2.70	31

Table 4: Index properties of samples collected for determination of the saturated hydraulic conductivity (Ks).

Sample No.	Sand (0.0625 - 2.00 mm) (%)	Silt (0.0039 - 0.0625 mm) (%)	Clay (<0.0039 mm) (%)	Plastic Limit (%)
1	37	52	11	26.8
2	12	65	23	26.3
3	1	81	18	24.4
4a	0	90	10	25.9
4b	0	90	10	25.9

Plastic limits show limited variation within the profile with values of between 24.4% and 26.8% for all samples (Table 4). Liquid limits, however, were unable to be determined as the high silt contents in the fine-grained fractions prevented creation of a proper groove when using the standard Casagrande grooving tool.

In general, it can be said that increasing effects of weathering processes up the profile are marked by a decrease in silt contents and an increase in clay contents.

Saturated hydraulic conductivity (Ks)

The permeability tests were all carried out with a constant head of 70.485 cm and involved measurement of the volume of water (cm^3) collected in fixed time periods (mins) at different elapsed times (in hours) from the start. The results of these tests are presented in Tables 5 to 9 in order to serve as references for future work.

The influence of texture on hydraulic conductivity is seen in the results of the sample from sub-zone IIA B which has only indistinct relict foliation planes but a relatively high sand content (37%). The sample thus shows a relatively high saturated conductivity (Ks) of 0.2977 cm/hr with the discharge becoming constant after some 4.5 hours.

The influence of relict foliation on hydraulic conductivity is seen in the results of the two samples from sub-zone IIB which were collected with the foliation planes

Table 5: Results of constant head permeability tests on Sample 1 from sub-zone IIA.

Time from start (hours)	Discharge (cm^3/hr)	Saturated Hydraulic Conductivity (Ks) (cm/hr)
0.083	240.00	0.3002
0.217	238.50	0.2984
0.433	234.46	0.2933
4.467	240.00	0.3002
4.550	237.60	0.2972
4.717	235.20	0.2942
8.783	232.50	0.2909
8.883	238.00	0.2977

Table 6: Results of constant head permeability tests on Sample 2 from sub-zone IIB. Flow perpendicular to relict foliation planes.

Time from start (hours)	Discharge (cm^3/hr)	Saturated Hydraulic Conductivity (Ks) (cm/hr)
0.117	47.14	0.0590
0.417	48.33	0.0605
0.800	49.04	0.0614
1.383	49.37	0.0618
6.067	48.00	0.0601
6.800	48.41	0.0606
7.600	48.50	0.0607
11.650	50.00	0.0601
11.767	49.71	0.0611

about perpendicular to the length of the sampling tube. Flow of water was thus about perpendicular to the inherent alignment of platy mineral grains and this is reflected in the low rates of discharge both at the start and for some time after (Tables 6 and 7). The samples thus show very low values of the saturated hydraulic conductivity (Ks) of 0.0611, and 0.0838, cm/hr, with the discharge being constant after some 4.5 hours.

The over-riding influence of relict foliation on hydraulic conductivity is best seen in the results of sample 4a from sub-zone IIC which was collected with the relict foliation parallel to the length of the sampling tube. Flow of water

Table 7: Results of constant head permeability tests on Sample 3 from sub-zone IIB. Flow about perpendicular to relict foliation planes.

Time from start (hours)	Discharge (cm^3/hr)	Saturated Hydraulic Conductivity (Ks) (cm/hr)
0.100	75.00	0.0938
0.283	73.64	0.0921
0.567	72.35	0.0905
4.683	68.57	0.0858
4.883	68.00	0.0851
5.200	66.63	0.0834
5.567	67.09	0.0839
9.617	68.00	0.0851
9.717	67.00	0.0838

Table 8: Results of constant head permeability tests on Sample 4a from sub-zone IIC. Flow parallel to relict foliation planes.

Time from start (hours)	Discharge (cm^3/hr)	Saturated Hydraulic Conductivity (Ks) (cm/hr)
0.017	750.00	0.9382
0.067	720.00	0.9007
0.167	715.00	0.8944
0.350	703.64	0.8802
4.517	633.00	0.7919
4.767	631.20	0.7896
5.050	631.06	0.7894
11.133	588.00	0.7356
11.283	586.67	0.7339
11.450	591.00	0.7393
11.717	588.75	0.7365

was thus preferentially along the inherent alignment of platy mineral grains and led to a fairly rapid rate of discharge which gradually reduced and became constant after some 11 hours of elapsed time (Table 8). This sample 4a thus has a saturated hydraulic conductivity (Ks) of 0.7365 cm/hr. Sample 4b from sub-zone IIC was collected with the relict foliation steeply inclined (60°) to the length of the sampling tube and thus shows a reduced rate of discharge (in comparison with sample 4a) which became constant after some 3 hours of flow (Table 9). A saturated hydraulic conductivity (Ks) of 0.2156 cm/hr was determined for sample 5b.

DISCUSSION

The results of the constant head permeability tests show that the saturated hydraulic conductivity (Ks) varies considerably within the weathering profile and is influenced primarily by the orientation of the inherent, relict foliation planes (Table 10). The particle sizes present also influence to some extent the hydraulic conductivity (Table 10). There is unfortunately no published data with which the results of this present study can be compared with.

Of indirect relevance to the present study would be the water absorption tests in boreholes in slightly weathered, friable meta-sedimentary bedrock carried out for the

Table 9: Results of constant head permeability tests on Sample 4b from sub-zone IIC. Flow inclined 60° to relict foliation planes.

Time from start (hours)	Discharge (cm^3/hr)	Saturated Hydraulic Conductivity (Ks) (cm/hr)
0.067	210.00	0.2627
0.167	202.00	0.2527
0.350	197.45	0.2470
0.583	195.86	0.2450
2.650	187.50	0.2346
2.783	183.75	0.2299
3.067	178.24	0.2230
3.383	177.79	0.2224
7.450	177.00	0.2214
7.567	176.57	0.2209
7.750	172.36	0.2156

Table 10: Saturated hydraulic conductivity (Ks) of samples from the weathering profile over quartz-mica schists of the Seremban area.

Sample No.	Vertical Depth (m)	Sub-zone	Flow relative to relict foliation planes	Ks (cm/hr)
1	6.07	IIA (Saprock)	Indistinct relict foliation - sandy	0.298
2	7.47	IIB (Saprock)	Perpendicular	0.061
3	10.74	IIB (Saprock)	About perpendicular	0.084
4a	15.05	IIC (Saprock)	Parallel to foliation	0.737
4b	15.05	IIIC (Saprock)	Inclined (60°)	0.216

Cameron Highlands Hydro-Electric Scheme (Dickinson & Gerrard, 1963). These tests yielded coefficients of permeability ranging from 0.324 to 4.32 cm/hr (90 to 2,000 ft/year); a range that encompasses most of the results of the present study (Table 10).

Constant head permeability tests on a schist saprolite (sub-zone IC) furthermore, were reported to gave a saturated hydraulic conductivity (Ks) of 1.10 cm/hr (Hamdan *et al*., 2009) The investigated sample was described as a clay loam with a bulk density of 1.30 g/cm^3, total porosity of 42%, moisture content of 15.6%, and consisted of some 30%, 35% and 35%, of sand, silt and clay sized particles, respectively. Although the reported hydraulic conductivity (Ks) of 1.10 cm/hr is fairly close to the conductivity values determined in the present study (Table 10), it must be noted that the samples (of the present study) were collected from the saprock which is morphologically located at depth below the saprolite.

The influence of foliation planes on the saturated hydraulic conductivity (Ks) is a factor of importance when desk-top studies and/or field investigations are carried out on the movement of subsurface water in areas of schist bedrock in Peninsular Malaysia. In view of the deep weathering profiles present, the infiltration and percolation of surface water will be preferentially along inherent relict foliation planes as will be the movement of groundwater and seepage from surface sources. At the same time, it is to be noted that movement of groundwater and seepage from surface sources will be very slow in directions perpendicular to the inherent relict foliation planes. Geological field mapping and determination of the orientation of foliation planes and other geological structures will therefore allow for patterns of groundwater movement and seepage to be predicted.

CONCLUSION

Laboratory constant head permeability tests conducted on samples collected within the weathering profile over quart-mica schists in the Seremban area show clayey silts from saprock sub-zone IIB with distinct relict foliation planes to have saturated hydraulic conductivities (Ks) of 0.0611, and 0.0838, cm/hr with flow perpendicular, and about perpendicular, to the foliation, respectively. Sandy silt from saprock sub-zone IIA with indistinct relict foliation planes has a saturated conductivity of 0.2977 cm/hr, whilst silts from saprock sub-zone IIC with distinct relict foliation planes have conductivities of 0.7365, and 0.3864, cm/hr with flow parallel, and steeply inclined, to foliation, respectively.

It is concluded that the saturated hydraulic conductivity (Ks) of earth materials within the weathering profile over quartz-mica schists is primarily dependent upon the orientation of their inherent relict foliation planes.

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