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Saturated hydraulic conductivity (Ks) of earth materials in a weathering profile over the Kuantan Basalt, Pahang, Malaysia

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Abstract: Three broad morphological zones can be differentiated at the weathering profile; the top, 3.80 m thick, pedological soil (zone I with sub-zones IA, IB and IC) comprising soft to stiff, brown clays and the bottom bedrock (zone III) being an outcrop of vesicular olivine basalt. The intermediate zone II (saprock) is 1.12 m thick and consists of brown, very stiff, sandy clayey silt with many lateritic concretions. Laboratory constant head permeability tests show the saturated hydraulic conductivity (Ks) to vary with depth; sub-zone IB having a conductivity of 0.007 cm/hr, and sub-zone IC (saprolite), and zone II (saprock), having conductivities of 0.147, and 0.447, cm/hr, respectively. The conductivity values show no correlation with physical properties of the earth materials, but increase with increasing sand, gravel, and silt, contents. The conductivity values also decrease with increasing clay and colloid contents. The low hydraulic conductivity of sub-zone IB will lead to surface runoff and ponding over natural ground surfaces during rainfall events, though over disturbed ground surfaces, infiltration is anticipated in view of exposed saprolite and saprock earth materials with relatively high conductivity.

Keywords: Weathering profile, Kuantan Basalt, 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 (A) of porous medium is directly proportional to the hydraulic gradient (i) normal to that area; 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.

There is limited published data on the saturated hydraulic conductivity 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). Limited data is particularly evident in the case of weathering profiles over basic igneous bedrock; there only being a single published paper to date. Hamdan *et al.* (2006) reported that samples of saprolite (soil horizon C) were collected from 16 locations over granite, schist, shale and basalt in Peninsular Malaysia to evaluate their potential use as a wastewater treatment. Infiltration rates both *in-situ*, and in the laboratory, were determined as were water retention curves using the pressure plate method. Saturated hydraulic conductivity (Ks) was also determined in the laboratory using the constant head method. The study showed that granite saprolite had the highest saturated hydraulic conductivity (Ks), and *in situ* field infiltration rate, of 6.5, and 4.0, cm/hr, respectively, whilst the basalt saprolite had the lowest corresponding values of 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 saturated hydraulic conductivity, and 0.60, and 0.06 cm/hr, for field infiltration rate, respectively. Clay and sand contents as well as porosity, pore shape and pore size were found to influence the hydraulic conductivity; the study concluding that shale and basalt saprolites would be suitable for use as *in situ* wastewater treatment due to the low saturated hydraulic conductivity (Hamdan *et al.*, 2006).

In the course of a study on the characterization of weathering profiles in Malaysia, Raj (1983) has investigated a profile developed over the Kuantan Basalt. The characterization of this profile, based on field mapping and the visual differentiation of morphological zones and sub-zones followed by laboratory determination of their physical and index properties, has been earlier discussed (Raj, 2021). In this paper are presented the results of determination of the saturated hydraulic conductivity (Ks) of earth materials within the weathering profile.

METHODOLOGY

The investigated weathering profile was exposed along the Kuantan - Jabor trunk road, close to the overhead bridge of the Kuantan Bypass Highway during excavation works for widening of the road shoulder (Figure 1). The cut is located on the side of a small valley with fresh basalt outcropping in the stream bed. Field mapping was first carried out to identify weathering zones and sub-zones, i.e. layers of earth materials with similar morphological features including color, texture, concretions, relict bedrock structures and core-boulders. Two sets of constant volume samples were then collected at vertical depths of 0.78 m, 2.65 m and 4.36 m; one set for determination of physical and index properties of the earth materials, and the other for determination of the saturated hydraulic conductivity (Ks) (Figure 2 and Plate 1).

Brass tubes of 4.0 cm length and 7.6 cm internal diameter were used for collection of each set of samples; the tubes having a wall thickness of 0.3 cm, except towards one end where the lower 1.5 cm tapered to a thickness of 0.15 cm to provide a cutting edge. Prior to sampling, the tubes were externally greased to facilitate entry into the soil whilst surface materials were cleared to a depth of about 0.5 m to minimize surface disturbance. The exposed earth materials were also cut into an approximately cylindrical shape, slightly larger than the tube diameters, prior to sampling to reduce lateral compaction. A sampling tube with the cutting edge facing downwards was first driven

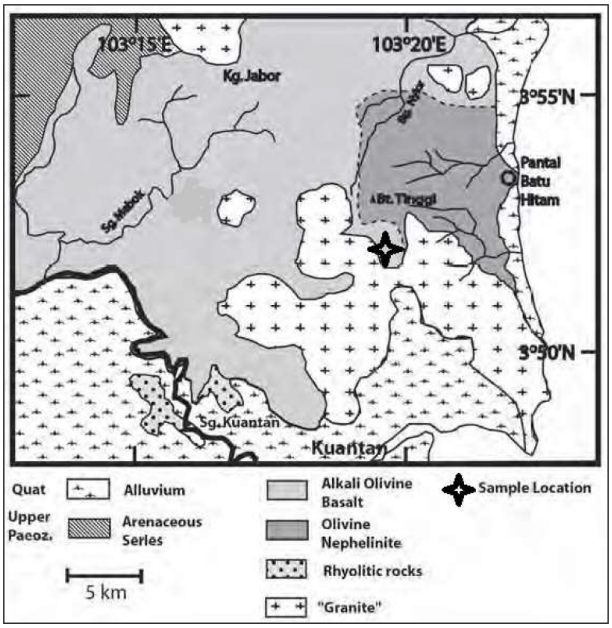

Figure 1: Geological sketch map of the Kuantan area, Pahang (after Azman & Nur Iskandar, 2007).

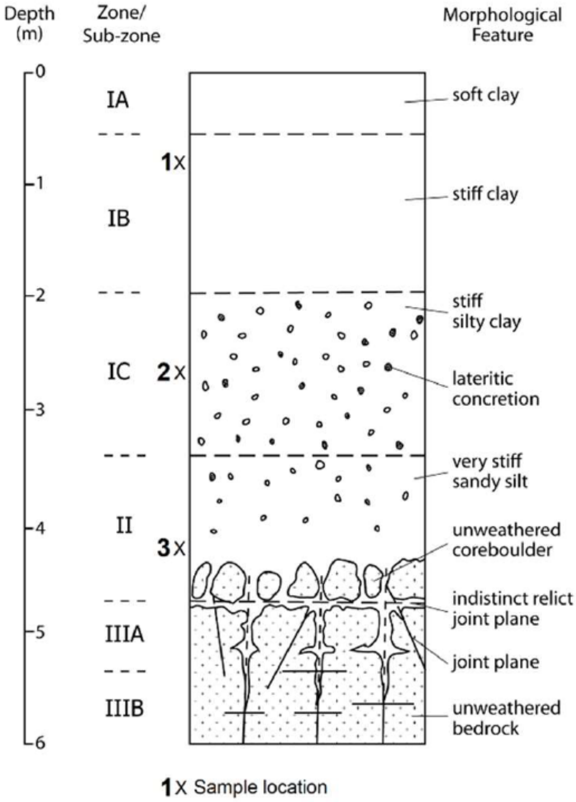

Figure 2: Schematic sketch of morphological features in the weathering profile with sample locations (1 to 3).

into the weathered material by gently hammering on its' top, until the top was flush with the ground surface. A second tube, with its cutting edge facing upwards, was then placed on the first tube and this then driven deeper into the soil by hammering gently on the top of the second tube. A piece of wood was placed on top of the tubes when hammering to minimize damage to the tubes as well as disturbance to the samples. Both tubes were then dug out from the ground by excavating the earth materials surrounding, and under, the two tubes. The sample in the upper tube was discarded, while the sample in the lower (first) tube was trimmed until its upper and lower surfaces were flush with the top and bottom of the tube. The sample was then sealed with rubber end caps and taken to the laboratory. It is to be noted that two separate samples were collected at each sampling site.

Moisture contents, unit weights and densities of one set of the samples were then determined before the specific gravity of the constituent mineral grains was measured using a pycnometer (GBRRL, 1959). Porosities were calculated before the plastic limits of the fine fractions (<0.425 mm size) were determined by standard procedure (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 (<0.0625 mm), fractions respectively (GBRRL, 1959). It is to be noted that 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 sampling tube (from the second set) with filter paper and wire gauze screens before sealing it 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 14 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.

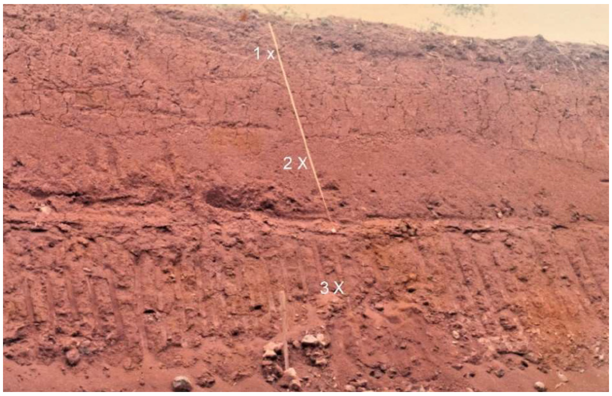

Plate 1: View of exposed weathering profile with sample locations (1 to 3). (Tape is 3.90 m in length).

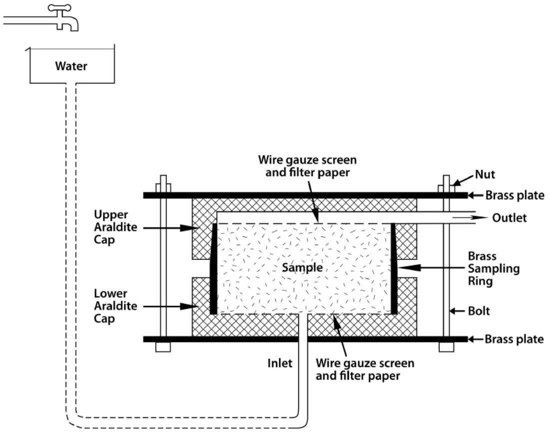

Figure 3: Schematic sketch of set-up for constant head permeability test.

GEOLOGICAL SETTING OF WEATHERING PROFILE

Basaltic lavas and dolerite dykes in the Kuantan area were first mapped and described in detail by the Geological Survey of Malaysia (Fitch, 1951). The basaltic lavas, covering an area of some 125 km^2, overlie, and surround, granite hills to the north and northwest of Kuantan, as well as overlie a sequence of Upper Paleozoic sedimentary-volcanic rocks (Figure 1). The dolerite dykes, ranging in thickness from 2 cm to about 5 m, mainly trend northeast to east and intrude the Upper Paleozoic and granitic rocks. The basaltic lavas are considered to result from fissure type eruptions; the center of extrusion near Bukit Tinggi, which at an elevation of 138 m above sea level, is the highest point where the basalts are found (Fitch, 1951). The basalts have also been considered to result from a central volcanic vent type eruption; the vent located at Bukit Tinggi (Bignell, 1972). Field mapping of the basalt furthermore, yielded paleo-flow directions that indicate the presence of two vents; one at Bukit Tinggi, and another at a hill located 1.9 km northwest of Bukit Ubi (Raj, 1990).

The dolerite dykes were first considered as feeder fissures to the basaltic lavas, though K-Ar dating of a dyke sample at 111 ± 4 Ma, and a basalt sample at 1.6 ± 0.2 Ma, indicated a long time interval between the two igneous events (Bignell & Snelling, 1977). The dolerite dykes and basaltic lavas furthermore, differ in petrology, age and paleo-magnetic directions, and are thus not genetically related (Haile *et al*., 1983). Several K-Ar radiometric dates yielding an average age of 1.7 ± 0.2 Ma clearly indicate the Quaternary occurrence of the Kuantan Basalt (Bignell & Snelling, 1977).

Initial work classified the Kuantan Basalt as an olivine basalt, both with and without nepheline (Fitch, 1951). A detailed study of thin-sections and several chemical analyses, however, concluded that the Kuantan Basalt involved two distinct and perhaps independent magma types, namely alkali olivine basalt magma and olivine nephelinite magma (Chakraborty, 1977). The olivine basalts were largely present in the western part of the Kuantan area, whilst the olivine nephelinites were restricted to the eastern part. The sequence of eruptions is not known, though olivine nephelinite appeared, at least in part, to be later than olivine basalt (Chakraborty, 1979).

A study of trace elements in the Kuantan Basalt noted that the olivine basalt and olivine nephelinite are both enriched in incompatible and light rare earth elements; signatures comparable with Oceanic Island basalts and East African Rift basaltoids. It was thus concluded that the geochemical evidence, as well as the timing, pointed to a mantle plume-related genesis for the Kuantan Basalt, rather than one related to wrench tectonics-induced extension (Azman & Nur Iskandar, 2007).

At the investigated weathering profile, the exposed bedrock is a black to dark green, micro-crystalline, vesicular olivine basalt with horizontal and vertical joints. In thin-sections, the basalt is seen to be composed of calcic plagioclase, augite, olivine, magnetite and limonite. The texture is normally inter-granular with augite crystals occupying the spaces between plagioclase laths. Sub-ophitic textures are also seen in some coarser grained varieties where the euhedral phenocrysts show little or no corrosion and consist mainly of olivine and rarely of plagioclase.

MORPHOLOGICAL ZONES AND SUB-ZONES IN THE WEATHERING PROFILE

Vertical variations in colour, texture and preservation of original bedrock structures allowed differentiation of three broad zones; an upper pedological soil (zone I), an intermediate saprock (zone II), and the underlying bedrock (zone III) (Table 1 and Figure 2). The zones are developed approximately parallel to the overlying ground surface and are similar to those differentiated in earlier studies of weathering profiles over the Kuantan Basalt (Hamdan *et al*., 2000; 2003).

The pedological soil is 3.6 m thick and can be separated into IA, IB and IC soil horizons; the IA and IB horizons constituting the solum, and the IC horizon, the saprolite (Table 1). The IA and IB horizons are relatively thin and comprise soft to stiff, brown clays, whilst horizon IC is 1.52 m thick and consists of a stiff, brown silty clay with many lateritic concretions.

The saprock is only 1.12 m thick and consists of a very stiff, brown sandy clayey silt with many gravel sized lateritic concretions and a few core-boulders towards its bottom (Table 1). The bedrock is a continuous outcrop of basalt and can be separated into an upper sub-zone (IIIA) with effects of weathering along and between joint planes, and a lower sub-zone (IIIB) with effects of weathering along joint planes (Table 1).

Seepage was not observed at the time of investigation, though an unconfined groundwater table is expected at

Table 1: Field description of morphological zones and sub-zones in the weathering profile.

Zone & Sub-zone	Depth (m)	Field Description
IA	0.00 - 0.60	Brown (7.5YR4/4), soft clay; porous; crumbly dry; many roots; some burrows; boundary wavy, diffuse
IB	0.60 - 2.08	Brown (7.5YR4/4), stiff clay; sub-angular blocky moist; friable dry; some large roots; few burrows; boundary wavy, diffuse
IC (Saprolite)	2.08 - 3.60	Brown (7.5YR4/4), stiff silty clay; sub-angular blocky moist; many lateritic concretions; boundary wavy, clear.
II (Saprock)	3.60 - 4.72	Brown (7.5YR4/4), very stiff, sandy silt; many gravel sized, lateritic concretions; sub-angular blocky moist; core-boulders in lower part; indistinct relict joint planes; boundary irregular, diffuse
IIIA (Bedrock)	4.72 - 6.61	Basalt with weathering (staining & alteration to sandy silt) along and between discontinuity planes; boundary irregular, diffuse
IIIB (Bedrock)	>6.61	Basalt outcrop with effects of weathering only along discontinuity planes only.

shallow depth in view of the adjacent perennial stream whose bed is some 5 m vertically below the road shoulder level.

RESULTS OF LABORATORY TESTS

Physical properties of sampled earth materials

The sampled earth materials, although all brown in colour with somewhat similar textural features (Table 2), show some differences in physical properties (Table 3). Sub-zone IC (saprolite) has the highest dry unit weight of 12.36 kN/m^3, whilst sub-zone IB, and zone II, have dry unit weights of 10.80, and 11.50, kN/m^3, respectively. Values of dry density are similar to those of dry unit weight; the saprolite with a dry density of 1,260 kg/m^3, and sub-zone IB, and saprock, with dry densities of 1,101, and 1, 172, kg/m^3. The specific gravity of constituent soil particles is similar (2.73) for the samples from sub-zones IB and IC, but slightly higher for the saprock sample (2.75) due to the lateritic concretions present (Table 3).

Porosity is variable with the saprolite having the minimum value of 53.8%, whilst sub-zone IB, and saprock, have porosities of 59.7%, and 57.4%, respectively (Table 3). Void ratios are similar to those of porosity with saprolite having the minimum value of 1.16, and sub-zone IB, and saprock, having values of 1.48, and 1.36. Moisture contents show a limited variation and range from 39.5% to 49.0% (Table 3).

Index properties of sampled earth materials

Grain size analyses show distinct differences with the saprock (zone II) having relatively large silt and sand contents, whilst sub-zone IB sample has a predominantly clay content, and sub-zone IC (saprolite), large clay and silt contents (Table 3). Fine clay (<0.002 mm size) contents are distinctly variable with sample sub-zone IB having the largest content (73%), whilst the saprolite, and saprock, samples have contents of 35%, and 19%, respectively (Table 3). Colloid (<0.001 mm size) contents are also distinctly variable; the sub-zone IB sample having the largest content of 68%, and the saprock and saprolite samples with contents of 30%, and 15% (Table 3).

Plastic limits of the fine fractions (<0.42 mm size) range from 40.6% to 48.7%, whilst liquid limits are only

Table 2: Descriptions of sampled earth materials.

Sample Number	Sub-zone	Vertical Depth	Description
1	IB	0.78 m	Brown, stiff clay.
2	IC	2.65 m	Brown, stiff silty clay.
3	II	4.36 m	Brown, very stiff, sandy clayey silt with many gravel sized, lateritic concretions.

Table 3: Physical properties of sampled earth materials.

Sample	Vertical Depth	Zone/ Sub-zone	Dry Unit Weight (kN/m^3)	Dry Density (kg/m^3)	Mineral Grain SG	Porosity (%)	Void Ratio	Moisture Content (%)
1	0.78 m	IB	10.80	1,101	2.73	59.7	1.48	49.0
2	2.65 m	IC	12.36	1,260	2.73	53.8	1.16	39.5
3	4.36 m	II	11.50	1,172	2.75	57.4	1.36	45.0

Note: SG refers to specific gravity.

Table 4: Index properties of sampled earth materials.

Sample	Vertical Depth	Gravel (%)	Sand (%)	Silt (%)	Total Clay (%)	Fine Clay (%)	Colloids (%)	Plastic Limit (%)	Liquid Limit (%)
1	0.78 m	0.2	7.8	16.0	76	73	68	48.7	70.0
2	2.65 m	5.2	22.7	34.1	38	35	30	42.2	63.5
3	4.36 m	7.8	27.1	43.1	22	19	15	40.6	ind

Note: Fine clay <2 μm size; Colloids <1 μm size; ind means indeterminate.

determinable for the sub-zone IB and saprolite samples are 70.0%, and 63.5%, respectively (Table 3). These results indicate that the samples would plot below the "A-line" in the Plasticity Chart of the Unified Soil Classification System and thus be classified as silty to sandy clays (Wagner, 1957).

Discharge and saturated hydraulic conductivity (Ks)

The permeability tests were carried out with constant heads of between 132 and 136 cm and involved measurement of the volume (cm^3) of water collected in fixed time periods (minutes) at different elapsed times (in hours) from the start. The results of these tests are presented in Tables 5 to 7 to serve as reference for future work.

The sub-zone IB sample (1) shows a gradual decrease in discharge with time and reaches a constant value after some 12 hours of elapsed time (Table 5). The saprolite sample (2) shows a similar gradual decrease in discharge with time and reaches a constant value after some 9 hours of elapsed time (Table 6). The saprock sample (3) starts with a fairly large discharge that quickly decreases and becomes constant after some 5 hours of elapsed time (Table 7).

Values of saturated hydraulic conductivity (Ks) calculated from the above results are presented in Table 8.

DISCUSSION

Comparison with published data

The limited published data available for comparison is from a basalt saprolite in the Kuantan area (Hamdan *et al.*, 2006). The investigated sample was described as a clay loam with a bulk density of 1.10 g/cm^3, total porosity of 40%, moisture content of 26.7%, and consisted of 16%, 30% and 54%, of sand, silt and clay sized particles, respectively. *In situ* field measurements yielded an infiltration rate of 0.03 cm/hr, whilst constant head

Table 5: Constant head (134 cm) permeability test on sample 1 from sub-zone IB.

Time from start (hours)	Discharge (cm^3/hr)	Saturated Hydraulic Conductivity (Ks) (cm/hr)
0.68	30.73	0.0202
1.88	22.08	0.0145
3.47	18.95	0.0125
7.57	12.44	0.0082
13.52	11.09	0.0073

Table 6: Constant head (132 cm) permeability test on sample 2 from sub-zone IC.

Time from start (hours)	Discharge (cm^3/hr)	Saturated Hydraulic Conductivity (Ks) (cm/hr)
0.08	660.0	0.4409
0.25	618.0	0.4128
0.50	580.0	0.3874
0.78	547.1	0.3654
2.78	450.0	0.3006
2.85	450.0	0.3006
3.03	420.0	0.2806
3.33	396.7	0.2650
3.78	377.8	0.2523
6.32	240.8	0.1608
9.40	220.5	0.1473
14.02	219.9	0.1469

laboratory tests gave a saturated hydraulic conductivity (Ks) of 0.10 cm/hr. A study of the shapes and sizes of the pores present indicated that the basalt saprolite was not very porous with low amounts of micro-, and meso-, pores, and extremely few macro-pores. The high clay content was considered responsible for the low volume of pores as well as relatively low values of infiltration rate and hydraulic conductivity (Hamdan *et al.,* 2006).

The saturated hydraulic conductivity (Ks) of 0.147 cm/hr determined for the saprolite sample in the present study can be correlated directly with the reported rate of 0.10 cm/hr by Hamdan *et al.* (2006). The saprolite samples of the present study furthermore, has fairly similar physical and soil index properties as those of the sample investigated by Hamdan *et al.* (2006).

Saturated hydraulic conductivity (Ks) and properties of sampled earth materials

Regression analyses yield low to very low, correlation coefficients (R^2) when values of saturated conductivity are plotted against physical properties of the earth materials. Plots of hydraulic conductivity versus dry unit weight for instance, yield an extremely low coefficient (R^2=0.0643), as do plots of hydraulic conductivity versus porosity (R^2=0.0353).

Plots of hydraulic conductivity versus index properties of the earth materials, however, yield variable trends with moderate to large, correlation coefficients (R^2) even with the limited number of samples involved. Positive trends for instance, with moderate correlation coefficients are seen when conductivity values are plotted against sand and gravel contents (R^2= 0.7888), and silt contents (R^2=0.8491) (Figures 4 and 5). Saturated hydraulic conductivity (Ks) is thus expected to increase with an increase in the gravel, sand and silt contents.

Plots of hydraulic conductivity versus clay contents furthermore, yield a negative trend with a fairly large correlation coefficient (R^2=0.8198) (Figure 6). Negative trends are also found when hydraulic conductivity is plotted against fine clay (R^2=0.8198), and colloid,

Table 7: Constant head (136 cm) permeability test on sample 3 from saprock (zone II).

Time from start (hours)	Discharge (cm^3/hr)	Saturated Hydraulic Conductivity (Ks) (cm/hr)
0.05	1520.0	0.9855
0.13	1260.0	0.8169
0.30	1170.0	0.7586
0.55	1124.0	0.7287
0.88	1092.0	0.7080
1.32	1059.2	0.6867
1.92	1008.3	0.6537
2.78	933.5	0.6052
3.93	867.8	0.5626
5.40	807.3	0.5234
7.43	729.3	0.4729
10.77	690.0	0.4474

Table 8: Saturated hydraulic conductivity (Ks) of earth materials from the weathering profile.

Sample	Depth (m)	Sub-zone/Zone	Ks (cm/hr)	Earth Materials
1	0.78 m	IB	0.007	Clay
2	2.65 m	IC	0.147	Silty clay
3	4.36 m	II	0.447	Sandy silt

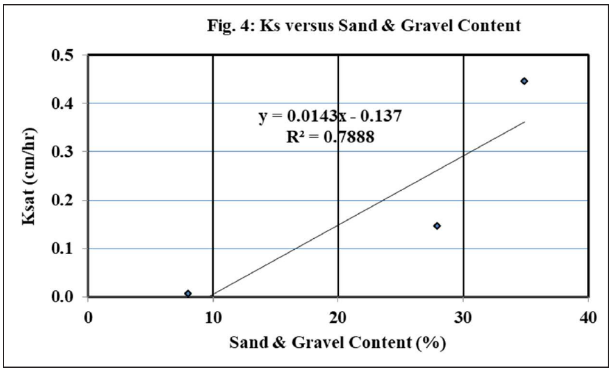

Figure 4: Saturated hydraulic conductivity (Ks) versus sand and gravel content.

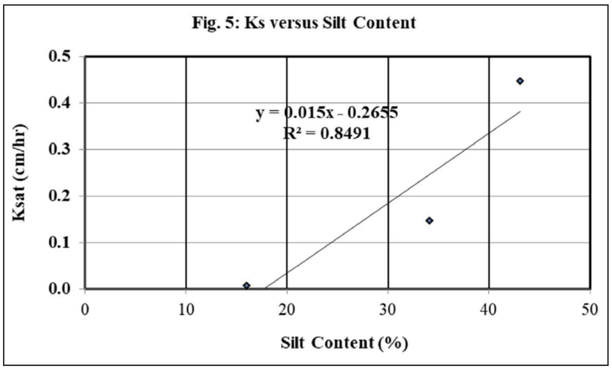

Figure 5: Saturated hydraulic conductivity (Ks) versus silt content.

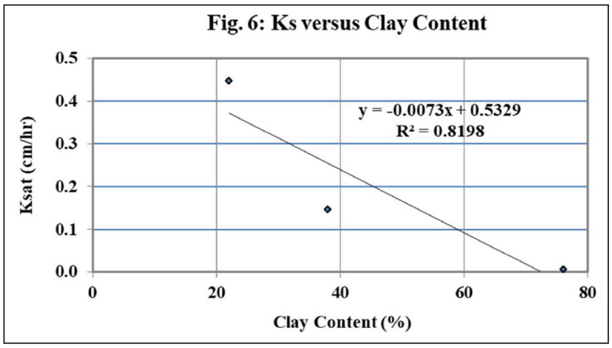

Figure 6: Saturated hydraulic conductivity (Ks) versus clay content

(R^2=0.8085), contents. Saturated hydraulic conductivity is thus expected to decrease with an increase in clay contents.

Variation of saturated hydraulic conductivity (Ks) within weathering profile

The results show the saturated hydraulic conductivity (Ks) to vary with depth; the IB sub-zone having a saturated hydraulic conductivity (Ks) of 0.007 cm/hr, the saprolite (sub-zone IC) a conductivity of 0.147 cm/hr, and the saprock (zone II) a conductivity of 0.447 cm/hr (Table 8). The upper pedalogical soil profile (zone I) thus has the lowest values of saturated hydraulic conductivity, whilst the lower saprock (zone II) has a relatively large conductivity. These variations will influence the infiltration and runoff of water during rainfall events over natural, and disturbed, ground surfaces over the Kuantan Basalt. In areas of undisturbed natural ground surfaces, ponding and surface runoff can be anticipated, though at slope cuts, and other areas of disturbed ground, there will be fairly rapid infiltration and percolation of rainwater.

CONCLUSION

Three broad morphological zones can be differentiated at the weathering profile; the top, 3.60 m thick, pedological soil (zone I) comprising brown, soft to stiff, clays. The intermediate saprock (zone II) is 1.12 m thick and consists of brown, very stiff, sandy clayey silt with many lateritic concretions, whilst the bottom bedrock (zone III) is an outcrop of vesicular olivine basalt with weathering along joints. Laboratory constant head permeability tests show the saturated hydraulic conductivity (Ks) to vary with depth; the IB sub-zone having a conductivity of 0.007 cm/hr, whilst the saprolite (sub-zone IC), and saprock (zone II) have conductivities of 0.147, and 0.447, cm/hr, respectively. The conductivity values show no correlation with physical properties of the earth materials, but increase with increasing sand and gravel contents, as well as increasing silt contents. The conductivity values also decrease with increasing clay contents. The low hydraulic conductivity of sub-zone IB will lead to surface runoff and ponding over natural ground surfaces during rainfall events, though over disturbed ground surfaces, infiltration is anticipated in view of exposed saprolite and saprock earth materials with relatively high conductivity.

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