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INFILTRATION CHARACTERISTICS OF UNSATURATED RESIDUAL SOILS OF VARIOUS WEATHERING GRADES

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Abstract. This paper presents the results of a field study on the infiltration characteristics of unsaturated residual soils of various weathering grades. Two field sites were studied, namely site A and site B. These sites respectively represent two of the most commonly occurring residual soils or rocks in Malaysia, that is the granitic residual soil and sedimentary (sandstone) residual soil. The water infiltration rate was found to vary depending on the soil weathering grades. For the case of granitic residual soils, soil of weathering grade IV was found to have the highest infiltration rate. Water infiltration was found to increase from grade VI to grade IV, and decrease from grade IV to grade III. Water infiltration was also found to increase with the increase in the soil porosity and void ratio, and decrease with the increase in the soil density. While for the case of sedimentary (sandstone) residual soil, the soil of weathering grade III was found to have the highest infiltration rate. Water infiltration was found to increase from grade V to grade III.

Keywords: Infiltration, landslide, porosity, residual soils, unsaturated soil, weathering

Abstrak. Kertas kerja ini memperihalkan kajian yang telah dibuat di lapangan mengenai ciri-ciri penyerapan air ke dalam tanah baki pelbagai gred yang tak tepu. Dua tapak ujian dikaji iaitu tapak A dan tapak B. Tapak-tapak ini mewakili tanah baki daripada batuan yang lazimnya terdapat di Malaysia, iaitu tanah baki granit dan tanah baki sedimen (batu kapur). Kadar penyerapan air didapati bergantung kepada darjah luluhawa tanah. Untuk tanah baki granit, tanah bergred IV didapati mempunyai kadar penyerapan air yang tertinggi. Kadar penyerapan ini didapati bertambah daripada tanah bergred VI ke gred IV, yang kemudiannya menurun daripada gred IV ke gred III. Kadar penyerapan air juga didapati bertambah dengan bertambahnya keliangan dan nisbah lompang tanah, dan menurun dengan meningkatnya ketumpatan tanah. Bagi tanah sedimen (batu kapur) pula, tanah bergred III didapati mempunyai kadar penyerapan yang tertinggi. Kadar penyerapan air didapati meningkat daripada tanah bergred V ke gred III.

Kata kunci: Keliangan, luluhawa, penyerapan, tanah baki, tanah runtuh

1.0 INTRODUCTION

Rainfall has been considered as the cause of the majority of slope failures and landslides that occurred in regions experiencing high seasonal rainfalls [1,2]. Basically, it is well known that infiltration impairs slope stability, but since it is often not measured

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off directly from the field, its assessment often relies on vague correlation with rainfalls and runoff. Correlation between rainfall and infiltration, thus slope stability, involves a large number of factors. Some of these factors, such as rainfall duration and intensity, slope surface cover and degree of saturation are extremely difficult to evaluate.

Conventionally, infiltration of water is not included in slope stability analysis. Many of the slopes were designed based on experiences. However, some attempts have been made to include rainwater infiltration and partial saturation in slope stability analysis [3-8]. In most of these analyses, the infiltration rate of the water into soil is assumed uniform throughout the slope. The soil is also assumed homogeneous except in some layered bedding problem. Most of the slope failure and landslides occurred after prolonged heavy rainfall or antecedent rainfall. The mechanism of the failures was mainly due to the lost of matric suction of soils by rainwater. When the rainwater infiltrates into the slopes, it will start to saturate the soil, i.e., reduce the matric suction. The wetting front of the rainwater will continue to move into the soil even after the rain had stopped. Movement of the wetting front stops when equilibrium condition is achieved.

Negative pore water pressure, which is also known as matric suction [9,10] is one of the main stress variables in unsaturated soil mechanic theory. The existence of matric suction will increase the strength of the soil. A deep ground water table condition is normal in hilly area. In this case, the negative pore water pressure or matric suction plays an important role in controlling the soil shear strength and consequently, the stability of many steep slopes. Shallow landslides often occur in steep residual soil slopes after heavy and prolonged rainfall. When water starts to infiltrate into the soil, the matric suction, especially near the ground surface will slowly reduce and become zero as the soil approaches saturated condition. The significant reduction in matric suction causes a decrease in the soil shear strength that subsequently produces shallow landslides.

In tropical countries such as Malaysia, residual soil forming processes are very active. Residual soils are products of the in-situ weathering of igneous, sedimentary and metamorphic rocks. The process of weathering varies with the depth or exposure of the soils. As weathering proceeds from the surface down and inwards from joint surfaces and other percolation paths, the intensity of the weathering generally reduces with increasing depths.

Most of the slopes in Malaysia that cut through the residual soil will expose the various weathering grades of the soil [11]. Due to the complexity of the weathering grades of the residual soil (which includes differences of particle size, density, mineral contents, cohesion and void ratios), the infiltration of the slopes is expected to vary from point to point down the slope.

This paper presents the result of a field study on the infiltration characteristics of unsaturated residual soils of various weathering grades. Two field sites were studied, namely site A and site B. These sites respectively represent two of the most commonly occurring residual soils/rocks in Malaysia, that is the granitic residual soil and sedimentary residual soil.

2.0 TEST SITES AND FIELD TESTS

2.1 Site A

Site A was a road cut made in a residual soil that had developed over the commonly outcropping Perm-Triassic Mesozonal granite of Peninsular Malaysia [12]. The particular road cut was at KM 31 along the Kuala Lumpur-Karak highway. The cross section of the cut slope is shown in Figure 1. The road cut has been made in

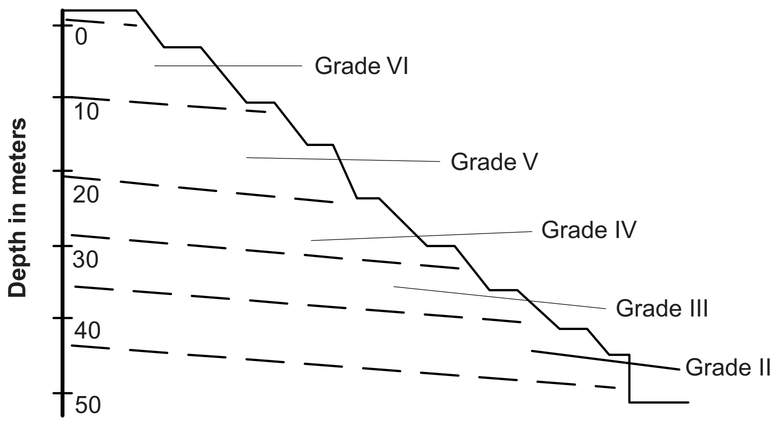

Figure 1 Weathering profile of the cut slope at site A

residual soil/rock of weathering VI to II, according to commonly used weathering classification for igneous and some sedimentary and metamorphic rocks, as shown in Table 1. Detailed description on the origin, formation, occurrence and typical properties of tropical residual soils can be found in Singh and Huat [13]. A typical weathering profile of a granitic rock is shown in Figure 2.

For measuring the soil infiltration rate, the Geonor P-88 infiltrometer was used. A schematic diagram of the test equipment is shown in Figure 3. The water level was kept constant in the test pit with cross sectional area of 25 × 25 cm. Water infiltrated into the soil through the walls and the bottom of the pit. Normally, the rate of the infiltrating flow will decrease during the test, until a steady state is achieved. This steady state flow was used to calculate the infiltration rate. The normal test duration was between 35 to 60 minutes.

The infiltration tests were carried out on soils of weathering grade III to grade VI. The test, however, could not be carried out on soil of weathering grade II since it consisted mainly of rock material.

Table 1 Classification of the weathering profile [14]

Weathering classification		
Term	**Grade**	**Description**
Residual soil	VI	All rock material is converted to soil; the mass structure and material fabric are destroyed; there is a large change in volume but the soil has not been significantly transported.
Completely weathered	V	All rock material is decomposed and/or disintegrated to soil; the original mass structure is still largely intact.
Highly weathered	IV	More than half of the rock material is decomposed and/or disintegrated to soil; fresh or discolored rock is present either as a discontinuous framework or as core stones
Moderately weathered	III	Less than half of the rock material is decomposed and/or disintegrated to soil; fresh or discolored rock is present either as a discontinuous framework or as core stones
Slightly weathered	II	Discoloration indicates weathering of rock material and discontinuity surfaces; weathering may discolor all the rock material.
Fresh rock	I	No visible sign of rock material weathering; perhaps slight discoloration on major discontinuity surfaces

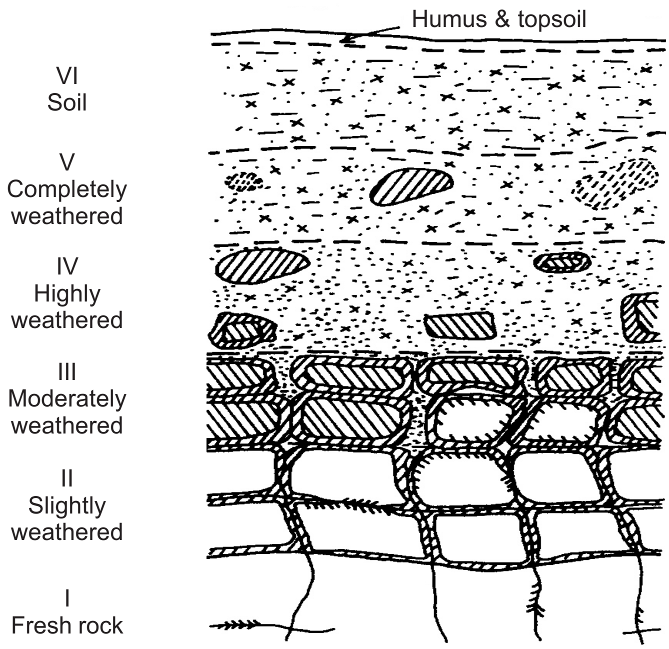

Figure 2 Typical weathering profile in granitic rock (after Little [15])

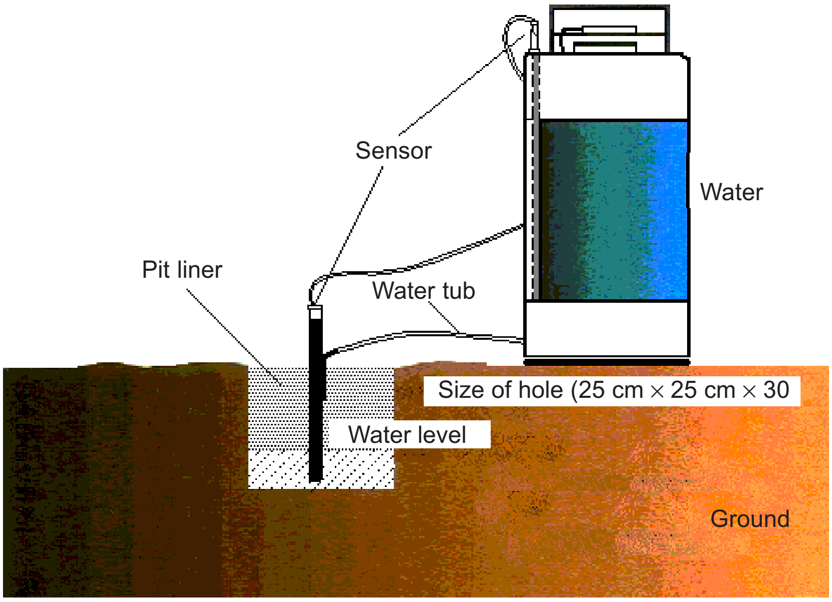

Figure 3 Field infiltration test using Geonor infiltrometer

2.2 Site B

Site B was a cut slope of approximately 40 m high along a link road near the Kuala Lumpur International Airport, Sepang, Malaysia. The slope basically comprised of residual soils of weathered sandstone. The soils were generally yellowish brown in colour and consist mainly of fine sand and silt.

The cut slope was mapped for the weathering grades, based on the commonly used classification of Little [15], and Komoo and Mogana [16].

Figure 4 shows a cross section of the cut slope. Based on the geological formation, the cut slope profile falls under the following weathering grades:

Berm 1 – Weathering grade V
Berm 2 – Weathering grade IV
Berm 3 – Intermediate weathering grade of IV and III
Berm 4 – Weathering grade III

In this study, an artificial rain was created on site using a sprinkler system. The sprinkler system was fabricated comprising of a 5 × 5 m sprinkling frame, made of steel tubes, PVC piping and sprinkler heads, as shown in Figure 5. Polythene sheets were used to enclose sides of the sprinkling/catchments area to minimise loss of water and direct surface run off to the collection drain.

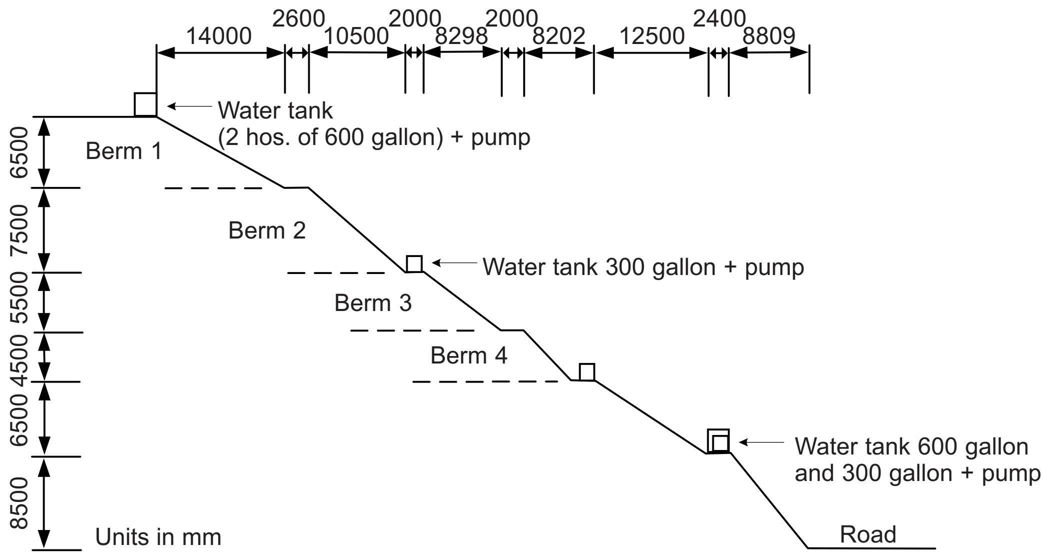

Figure 4 Sectional profile of the cut slope at site B

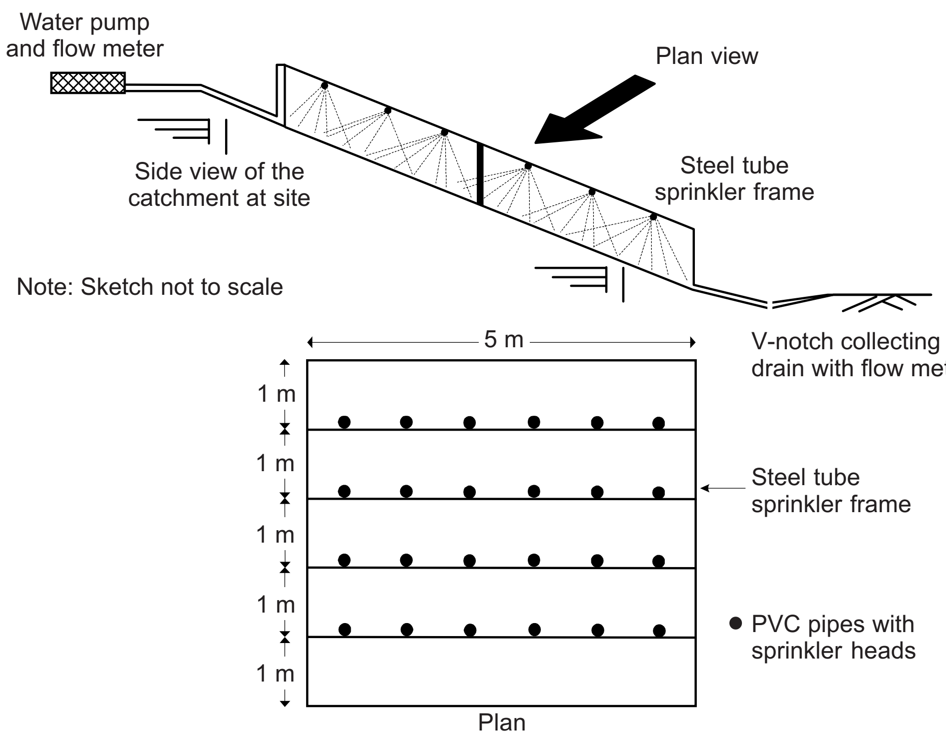

Figure 5 Sprinkling frame and locations of sprinkler heads

To monitor the rate of water inflow and regulate the flow to the test site, flow meters, as shown in Figure 6, were installed. This enabled the total volume of water supplied to the test locations to be measured. The excess (surface run off) water from the test site was in turn directed to v-notch collection drain, and measured using the flow meter at the outlet. The difference between the volumes of water supplied to the test site (i.e. for simulation of the artificial rain) and the surface run off is used to calculate the infiltration.

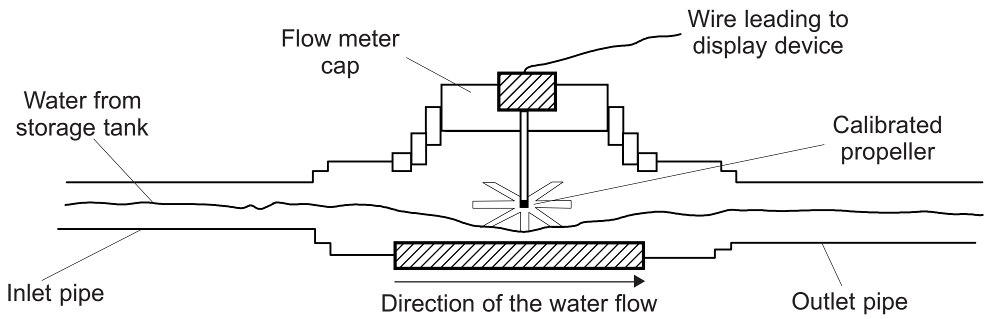

Figure 6 Working concept of a flow water

No study was made to compare the consistency of the methods used for the infiltration measurement at site A (i.e. using the field infiltrometer), and that of the site B using the rain simulator. Arguably however, it may be considered that the later method employed at site B would be more representative of the site conditions since the point of measurement encompasses a much wider area.

3.0 RESULTS AND DISCUSSION

Figure 7 shows a typical plot of infiltration rate versus time obtained from the field infiltrometer test at site A.

The infiltration rate is observed to be initially high and then stabilises at a lower value. This is due to the difference in the suction head in the soil. When the infiltration test is carried out, initially the surface of the test point (top layer) becomes wetter than the lower layer. The suction head, that is the downward forces due to the capillary effect and pressure head (moisture gradient) from the saturated top layer, and the gravity force acting on the water will force the water to infiltrate into the soil. At the beginning of the infiltration, the downward forces are large compared with the flow resistance of the soil, and water enters the soil rapidly. Nevertheless, with the passage of time, resistance caused by swelling of clay particles and entrapped air increases. Therefore, there is not much difference between the values of downward

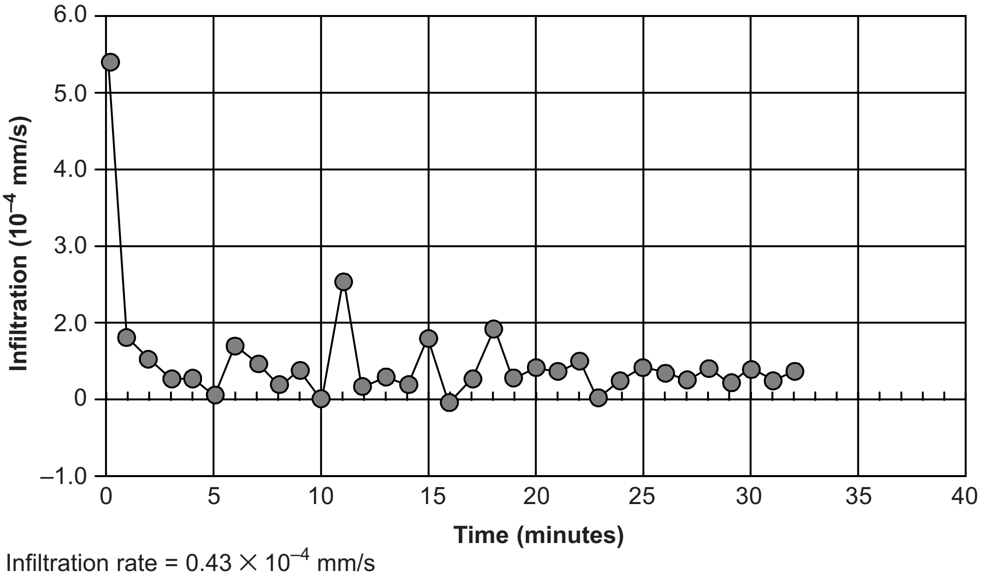

Figure 7 Infiltration rate of granitic residual soil of weathering III (upper boundary) at site A

forces and thus, the rate of infiltration reduces. When the downward forces and resistance have equalised, the rate of infiltration becomes constant and stabilised.

The stabilised infiltration rates of the granitic residual soils at site A are summarised in Table 2. The table shows that the infiltration rate varies from one weathering grade to another. The Grade IV materials show the highest infiltration rate. Moving from weathering VI to grade III, the infiltration rate increases and reduces after grade IV.

Table 2 Infiltration rates of granitic residual soils of various weathering grades at site A

Weathering grade	Infiltration rate (mm/s)	Porosity, n	Void ratio, e
Grade VI	0.84 X 10^{-4}	0.36	0.57
Grade V	1.22 X 10^{-4}	0.39	0.63
Grade IV	1.47 X 10^{-4}	0.51	1.04
Grade III upper boundary	0.43 X 10^{-4}	0.50	1.01
Grade III lower boundary	0.12 X 10^{-4}	0.46	0.85

The reasons for this could be explained by examining the soil parameters, namely soil porosity and void ratio, density and soil particle content, as shown in Table 3.

It can be seen from Table 3 that, soil of weathering grade IV has the highest porosity and void ratio, hence the larger infiltration rate compared with other grades.

Table 3 Basic engineering properties of the granitic residual soils at site A

	Grade VI	Grade V	Grade VI	Grade III	Grade III* - II
Specific gravity	2.61	2.63	2.59	2.59	2.60
Bulk density (Mg/m^3)	1.89	1.79	1.38	1.44	1.50
Dry density (Mg/m^3)	1.67	1.61	1.27	1.28	1.41
Void ratio	0.57	0.63	1.04	1.01	0.85
Porosity	0.36	0.39	0.51	0.50	0.46
Clay content %	48.1	17.3	6.8	5.4	4.4
Silt content %	8.8	25.7	11.3	22.0	26.9
Sand content %	43	51.3	77.2	70.8	58
Gravel content %	0.1	5.7	4.7	1.8	10.7

Note:- * Lower boundary of grade 3

High soil porosity or void ratios allow water to flow easily in the soil and ease the infiltration process. The water infiltration rate also decreases with the soil density. The higher the density, the denser the soil and lesser pores or water passage in the soil, thus the infiltration reduces.

As rock goes through the weathering processes to form residual soils, generally, the higher weathering grades would have soil with higher finer particles. Besides the soil properties mentioned above, fine particles play an important role in affecting the water infiltration. As shown in Table 3, a grade VI material has more fines (silt and clay) compared with the others. Kirby [17] suggested that the clay particles in the soil could experience swelling and block some of the pores or reduce the pore size in the soil structure during the water infiltration process.

Zone of weathering may also affect water infiltration. For the case of granitic residual soils, soils of weathering grade III have little amount of clay content but still have lower infiltration rate. In this zone, least amount of weathering has occurred (i.e. less than half of the rock material is decomposed), it seems that the water paths are less, thereby reducing the capacity of the water to infiltrate. It is of interest to note that parameters such as porosity are only relevant to the weathered materials that can be sampled, and therefore, do not necessarily represent the property of the entire zone. As shown in Table 1, less than half of the rock material has decomposed in this zone (i.e. the grade III).

Table 4 summarises the rate of infiltration of the sedimentary (sandstone) residual soils at site B, estimated based on the simulated rain and surface run off. It appears that the water infiltration rate increases from grade V to grade III. In this case, soil of weathering grade III (at berm 4) appears to have the highest infiltration rate indicating the more porous and permeable nature of this zone.

Table 4 Summary of soil infiltration rate of site B

Berm	Weathering grade	Infiltration rate (mm/s)
1	V	1.20×10^{-3}
2	VI	2.30×10^{-3}
3	IV – III	4.61×10^{-3}
4	III	6.91×10^{-3}

It is interesting to note that the sedimentary (sandstone) residual soils appear to have higher infiltration rates compared with the granitic residual soil, for their respective weathering grades. However, it must be pointed out that the two sites employed different methods for measuring the infiltration. As such a direct comparison must be treated with caution.

4.0 CONCLUSIONS

From the results of this study, the following conclusions could be drawn concerning the infiltration characteristics of residual soils of various weathering grades.

(a) The field infiltration measurement shows that infiltration rate is initially high then it stabilizes at a lower value.

(b) The infiltration rate is found to vary depending on the soil weathering grades. For the case of granitic residual soils of site A, soil of weathering grade IV is found to have the highest infiltration rate. Water infiltration is found to increase from grade VI to IV, and decrease from grade IV to grade III.

(c) The water infiltration is found to increase with the increase in the soil porosity and void ratio. High soil porosity or void ratios allow water to flow easily into the soil and ease the infiltration process. The water infiltration is found to decrease with the increase in the soil density. The higher the density, the lower the void ratio and porosity, thus the lower the water infiltration.

(d) Fine particles play an important role in affecting the water infiltration. For the case of the granitic residual soil, the grade VI material has more fines (silt and clay) compared with the others, thereby reducing the capacity of water to infiltrate.

(e) Zone of weathering may also affect the water infiltration. For the case of granitic residual soils, soils of weathering grade III have little amount of clay content but still have lower infiltration rate. In this zone, least amount of weathering has occurred (i.e. less than half of the rock material is decomposed), it seems that the water paths are less, thereby reducing the capacity of the water to infiltrate.

(f) For the case of sedimentary (sandstone) residual soil, soil of weathering grade III is found to have the highest infiltration rate. Water infiltration is found to increase from grade V to grade III, indicating an increase in porosity and available paths for the water to infiltrate.

(g) The sedimentary (sandstone) residual soils appear to have higher infiltration rates compared with the granitic residual soil, for their respective weathering grades.

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