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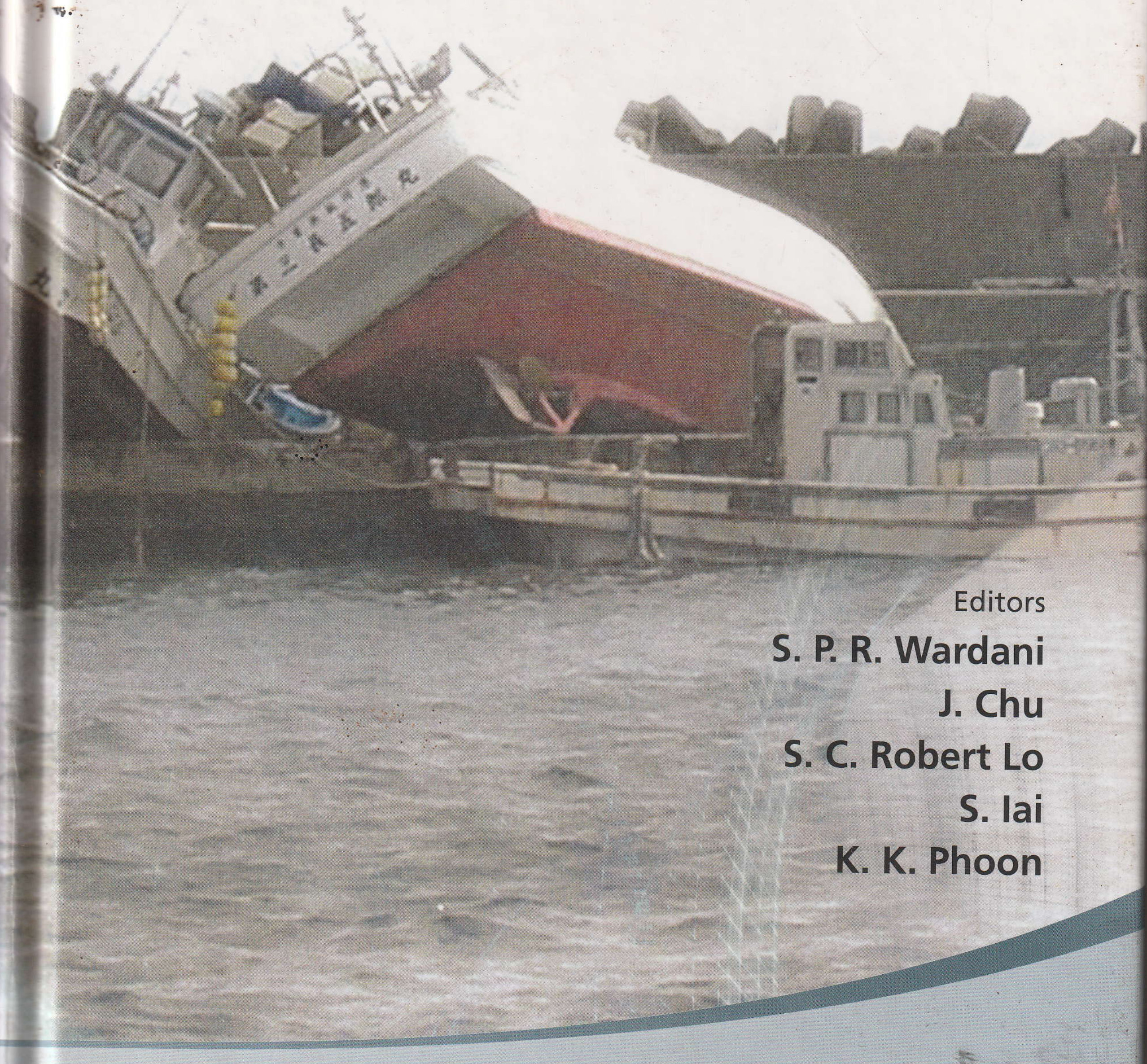
Geotechnical Engineering for Disaster Mitigation and Rehabilitation 2011

combined with the 5th International Conference on

Geotechnical and Highway Engineering – Practical Applications, Challenges and Opportunities



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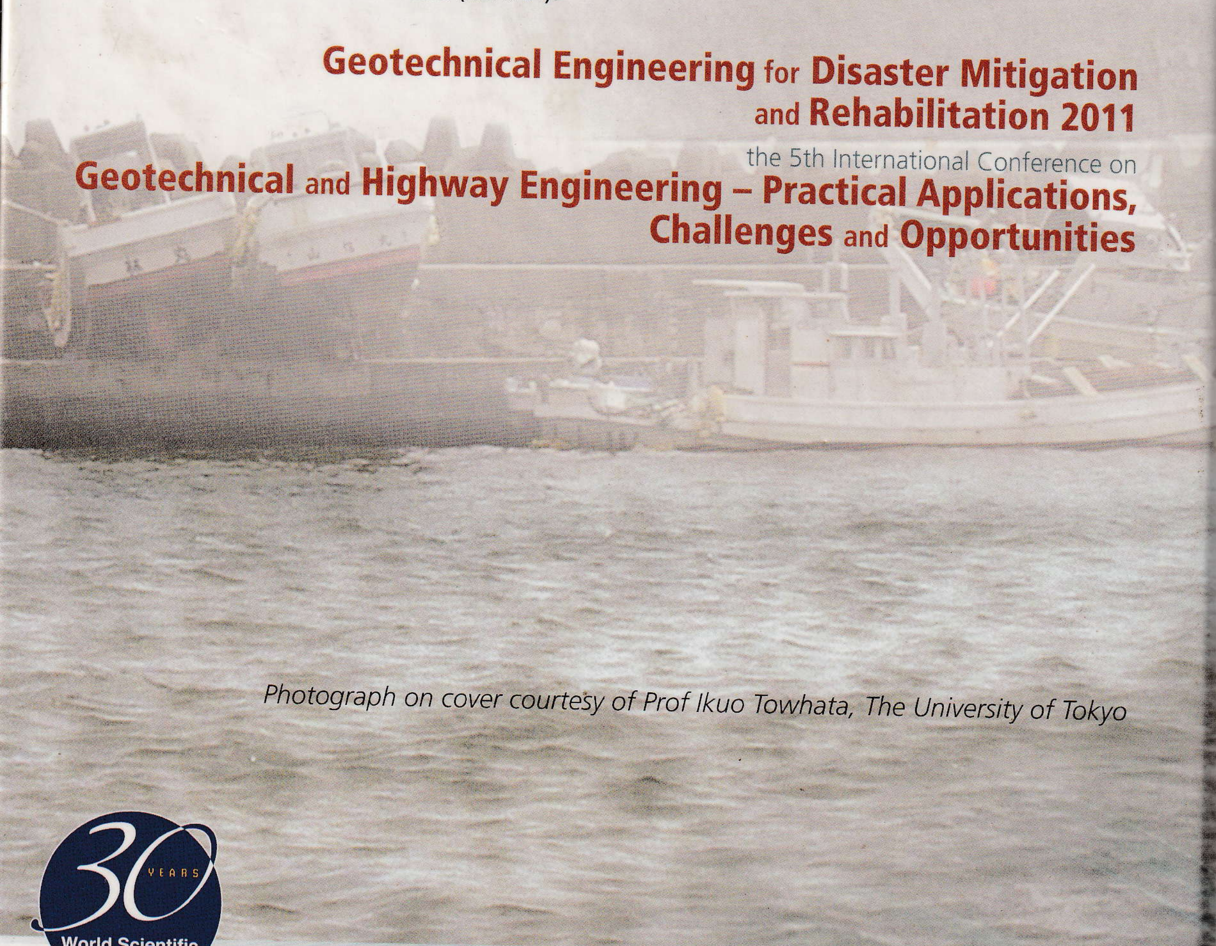
This proceedings contains 89 papers from 25 countries and regions, including 14 keynote lectures and 17 invited lectures, presented at the Third International Conference on Geotechnical Engineering for Disaster Mitigation and Rehabilitation (3ICGEDMAR 2011) together with the Fifth International Conference on Geotechnical & Highway Engineering (5ICGHE), which was held in Semarang, Indonesia, from 18 to 20 May 2011. This is the third conference in the GEDMAR conference series. The first was held in Singapore from 12 to 13 December 2005 and the second in Nanjing, China, from 30 May to 2 June 2008.

The proceedings is divided into three sections: Keynote Papers, Invited Papers and Conference Papers under which there are six sub-sections: Case Studies on Recent Disasters; Soil Behaviours and Mechanisms for Hazard Analysis; Disaster Mitigation and Rehabilitation Techniques; Risk Analysis and Geohazard Assessment; Innovation Foundations for Rail, Highway, and Embankments; and Slope Failures and Remedial Measures.

The conference is held under the auspices of the International Society for Soil Mechanics and Geotechnical Engineering (ISSMGE) Technical Committee TC-303: Coastal and River Disaster Mitigation and Rehabilitation, TC-203: Earthquake Geotechnical Engineering and Associated Problems, TC-302: Forensic Geotechnical Engineering, TC-304: Engineering Practice of Risk Assessment and Management, TC-213: Geotechnics of Soil Erosion, TC-202: Transportation Geotechnics, TC-211: Ground Improvement, Southeast Asian Geotechnical Society (SEAGS), Association of Geotechnical Societies in Southeast Asia (AGSSEA), and Road Engineering Association of Asia & Australasia (REAAA).



Geotechnical Engineering for Disaster Mitigation and Rehabilitation 2011

the 5th International Conference on

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Contents

EFFECT OF RELICT JOINT ON THE MASS PERMEABILITY OF RESIDUAL SOIL

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ABSTRACT

Permeability is a dominant factor affecting the suction distribution in unsaturated residual soil. However, determination of mass permeability of the residual soil is not a simple matter due to the process involved in the soil formation and the influence of geological structures. Weathering in parent rocks tends to form zones of material with different hydraulic conductivities. These heterogeneities significantly affect water movement in soils by creating a non-uniform velocity flow which is often referred to as preferential flow. Previous publications have highlighted the difficulties in generalizing the hydraulic properties of residual soils. This paper presents a laboratory method developed based on constant head test to determine the mass permeability of residual soil. Results show that the mass permeability of soil increases as the number of relict increases. In addition, comparison with field test data shows that the model gives a good prediction of mass permeability of the soil.

Keywords: saturated permeability, relict joint, residual soil, laboratory model

INTRODUCTION

Landslides induced by rainfall are common in tropical region where most of the areas are covered by residual soils and the average annual rainfalls are considerably high. The residual soils naturally exist in unsaturated condition because the ground water elevation is relatively deep. Most of the slope failures occur in the unsaturated soil zone or weathered substratum because their mechanical characteristics are significantly poorer than underlying bedrock. Study performed by Pradel and Raad (1993) showed that permeability of the soil plays an important role to determine the potential precipitation regime for slope failure. Furthermore, Gofar & Lee (2008) suggested that various types of soil would respond differently to certain rainfall characteristics depending on the ratio of rainfall intensity to the saturated permeability of the soil mass.

The behavior of tropical residual soils is complex due to the heterogeneity resulted from weathering process. These heterogeneities can significantly affect the permeability of the soil mass by non-uniform velocity flow process which is often referred to as preferential flow (Garga & Blight, 1987). Sources of heterogeneity in tropical residual soil profiles include micro-fabric and mineralogical variations at the *material scale*, and macro-structural features at the *field scale*. Through several case studies in Malaysia, Gue and Tan (2006) showed that many rainfall-induced slope failures in tropical residual soils are associated with relict discontinuities, e.g., relict joints, bedding planes, foliations, faults, and shears. As a macro-structural feature, relict joints are one of relict discontinuities normally preserved in the igneous saprolitic soils or weathered material inherited from the underlying parent bedrock (Aydin, 2006). Aydin also indicated the presence of corestone as another common form of heterogeneities. The corestone is defined by the occurrence of large particles (boulder and cobbles) in a matrix of a considerable smaller particles developed over jointed igneous rocks.

The presence of relict structures makes the behaviour of tropical residual soil slope far more complex. The influence of relict discontinuities on slope stability was studied by Irfan and Wood (1988) while the effect of relict structures and corestone on the shear strength and deformation of soil mass was investigated by Lindquist and Goodman (1994). However, limited study was conducted on the effect of these heterogeneities on the permeability of the soil. The purpose of conducting the test was to fundamentally demonstrate the effect of relict discontinuities on the mass permeability of the soil. Weathered materials at a location in Universiti Teknologi Malaysia (UTM) campus, known to have relict structure, were selected for the present study. Site investigation was performed on the site to identify the general soil profile. Besides taking samples for site characterization and laboratory test, field permeability tests were performed for verification of the laboratory data and analysis purposes.

SUBSURFACE CONDITION

Figure 1 shows the location of sample collection and field test. Overall, the geometry of the Balai Cerapan slope is uniform, and the slope appears to be a natural cut. The slope angle at the study area is approximately 21^{o} with an average length of 47 m. The slope face is well turf with Buffalo-Grass and scattered matured trees are found at the toe of the slope. Geologically, the Balai Cerapan site consists of gabbroic residual soils derived from the Intrusive Rock Pre-Granite Formation.

Figure 1: Location of field study and sample collection

Ground investigation was conducted with the aim of identifying the thickness of weathering zones, and structural elements in the residual soils. Boreholes were drilled at two locations, at the crest (BH1) and at the toe (BH2). The borelogs indicate that the subsurface is made up of three layers (Figure 2). The upper portion of the soil is totally weathered (Grade VI residual soils). The reddish-brown soil of this layer is classified by ASTM as sandy SILT (MS) with smooth-textured soil particles. The second layer consists of reddish-brown completely weathered (Grade V) rock. The most apparent manifestation of residual soil at this layer or saprolitic zone was the rough texture of soil particles. Based on ASTM classification, the soil is grouped as silty-GRAVEL (GM). Although relict joints were indistinctly observed due to the poor recoveries of soil sample during ground investigation, the occurrence of corestones of gabbroic rock were markedly identified in the upper portion of layer 2. The corestones appear randomly with average distance of 700mm (Figure 2). Highly to moderately weathered (Grade III to IV) rock was observed as the third layer. Apart from the presence of boulders, ASTM classifies the soil as silty SAND (SM).

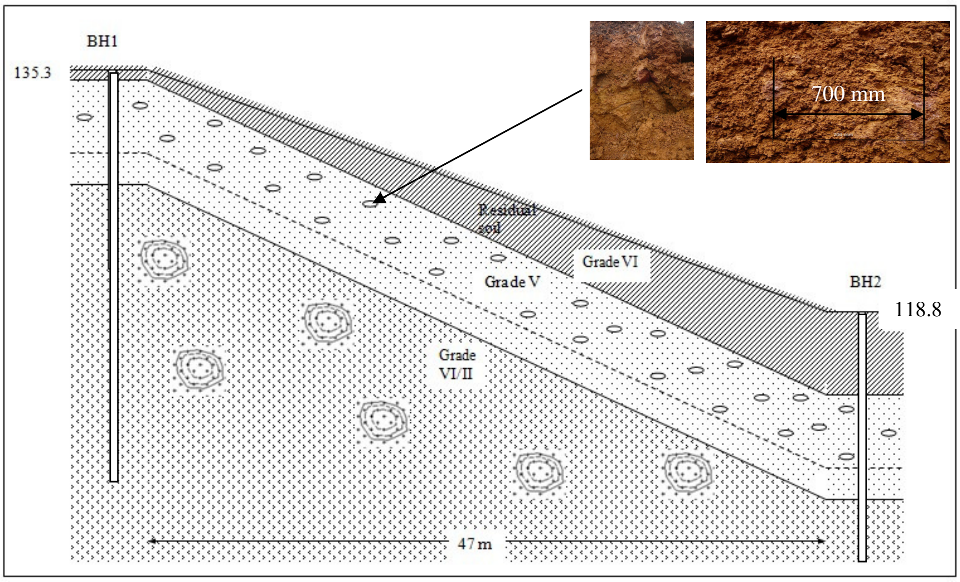

Figure 2: Soil profile and features of heterogenety in second layer (Grade V)

FIELD PERMEABILITY

Field permeability of the soil was performed by a Guelph constant head permeameter at arbitrarily spots and depths in the Grade V residual soils (Figure 3). Despite the maximum measuring depth suggested by the instruction manual is only 0.75 m, the measurements at deeper elevation were made possible by clearing the soils at upper layers. The procedure involves drilling a well by an auger and installation of the permeameter in the well. The first constant hydraulic head label is selected by adjusting the air inlet tube on the constant head device. By recording the rate of fall on the reservoir water scale, the steady state flow rate can be observed and noted. A second constant head level is then selected and the steady state flow rate is recorded. The rate of this constant outflow of water, together with the diameter of the well, and height of the water in the well can be used to precisely determine the field saturated conductivity of the soil.

Although the in-situ tests were carried out at all layers, only the results pertaining to layer 2 are of interest. Nine data sets revealed that the permeability varies despite the samples were taken from the same generalized layer. This is due to the existence of corestones at some portions of this layer of weathering Grade V (Figure 2). The values ranged between 6.12×10^{-6} m/s and 1.23×10^{-5} m/s, even the minimum value is higher than the previous field measurements published by Maail and Huat (2004) for tropical residual soils in Malaysia. This shows that the relict joint and corestone in Grade V soil may act as preferential seepage paths, resulting in high inflow rates.

LABORATORY EXPERIMENT

The effect of relict joint and corestones cannot be simulated in standard permeability mould. Thus, a special infiltration cell (Figure 4) was fabricated. The steel framed acrylic cell, 750 mm in length, 200 mm in height, and 150 mm in width, was designed based on the concept of constant head permeability test. Constant inflow was introduced at the top of the cell while outflow was collected at the bottom edge of the cell. A 25 mm thick layer of lightly compacted gravel of 5 mm size was placed uniformly at the bottom of the infiltration cell to catch the outflow before it is channeled to the drain.

Figure 3: Field Permeability test by Guelph Permeameter

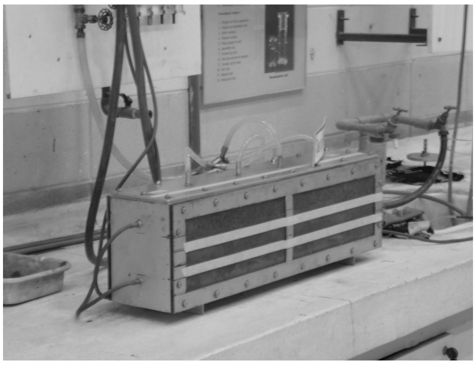

Figure 4: Laboratory model

Disturbed samples from Grade V residual soils (Layer 2) were used for the test. Sample preparation was done carefully to achieve the field density of the soil. In this case, oven dried sample was mixed with predetermined amount of water identical to the residual water content obtained from SWCC of the soil. The number of tamp required to achieve predetermined density was obtained from trial compaction on the soil. Artificial relict discontinuities were simulated by inserting a 1mm thick metal sheet into the soil at various spacing. Soil was poured into the cell carefully as not to move the position of the aluminum sheets. The soil was placed in layers of 50 mm thick. In order to maintain homogeneity, the surface of each layer was scarified before placement of the subsequent layer. Upon the soil placement and compaction of the final layer, the standing aluminum sheets were carefully pulled out from the compacted soil. This important step resulted in the formation of a very close opening of less than 1 mm that artificially representing relict joint within the soil mass. Another 25 mm thick layer of lightly compacted gravel of 5 mm size was placed uniformly at the top of the compacted soil before a steel plate cover was securely placed by tightly screwing the available nuts. Finally the inlet tubes were connected to the infiltration cell before the permeability tests was carried out. The procedures to perform constant head test as outlined by Head (1986) were adopted. The tests was terminated once the top and bottom pressure head of the soil have achieved constant readings. The experiment was performed for ten different spacing of relic joint ranging from 50 mm (spacing ratio 0.07) to 750 mm (no relict joint). Each set of test was performed three times.

RESULTS AND DISCUSSION

The results are summarized in Table 1 and Figure 5. As expected, the coefficient of permeability increases as spacing decreases. The data revealed that the permeability varies approximately one order of magnitude i.e. between 2.81×10^{-6} m/s for homogeneous soil mass (no relict) and 1.41×10^{-5} m/s (spacing 50 mm). This indicates the enormous influence of structural discontinuities on the soil permeability.

Table 1: Average saturated permeability with respect to the spacing of relic joint

Set No	Spacing (mm)	Coef of permeability k_{sat} (m/s)
1	50	1.41E-05
2	100	1.35E-05
3	150	8.69E-06
4	200	7.19E-06
5	250	5.42E-06
6	300	3.91E-06
7	350	3.43E-06
8	400	3.20E-06
9	450	3.07E-06
10	750	2.81E-06

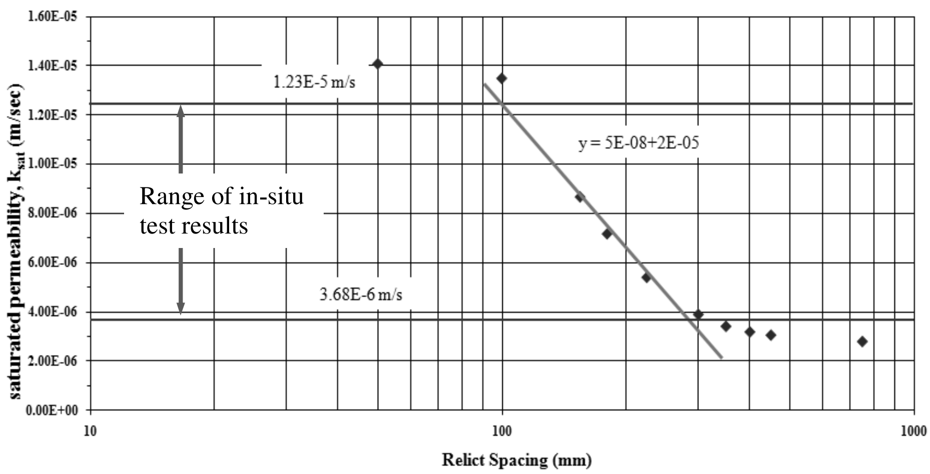

Figure 5: Effect of relic spacing on the saturated permeability of soil mass

Three different zones are identified from Figure 5 namely the boundary zones and transition zone. The permeability values obtained from laboratory test in the transition zone are in close agreement with the k_{sat} of Grade V residual soils obtained from the in-situ tests. It can be traced that the zone is representing the spacing of relict joint between 110 and 300 mm. Thus, linear relationship between the saturated permeability (k_{sat}) and logarithmic of spacing (s in mm) is applicable for the range of permeability obtained in-situ:

$$k_{sat} = \text{-}5 10^{-8} \log(s) + 2 10^{-5} m / \sec \qquad (1)$$

This implies that the presence of relict discontinuities within the soil mass of Grade V residual soil significantly affect the coefficient of saturated permeability. The more frequent the occurrence of the relict discontinuities, the higher the coefficient of saturated permeability. However, spacing wider that 300mm gives no effect on the permeability. On the other hand, spacing closer than 110mm results in a more dominant preferential flow and results in different flow pattern or mechanism. Note that the spacing used in the laboratory experiment do not necessarily represents the actual distance between two corestones shown in Figure 2 because their existence is randomly distributed and the length of permeability cell used in this study is only 750mm.

CONCLUSIONS

A laboratory model was developed to measure the mass permeability of residual soil containing some discontinuities i.e. relic joint. The influence of structural discontinuities was fundamentally displayed in the modified constant head tests to determine the effect of relic joint on saturated permeability, k_{sat} of the soil mass. The results show that the permeability of the residual soil in saprolitic zone profile was controlled by the structural discontinuities of the material. The results of laboratory experiment are in close agreement with the values of k_{sat} of Grade V found *in situ*. Both tests suggest that the occurrence of relic and corestones in Grade V material has significant effect on the saturated mass permeability of the residual soil.

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