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# Initial Surmises from a Field Study of Suction Behaviour of Tropical Unsaturated Residual Soils

**Harwant Singh**
*Fac. of Resource Science & Technology, Uni. Malaysia Sarawak,*
*94300 Kota Samarahan, Sarawak, Malaysia*
*terratee@frst.unimas.my*

**Bujang K. Huat**
*Dept. of Civil Engineering, Uni. Putra Malaysia,*
*43400 UPM Serdang, Selangor, Malaysia*

**Faisal Ali** and **S. Mariappan**
*Dept. of Civil Engineering, Uni. of Malaya, 50603 Kuala Lumpur, Malaysia.*

## ABSTRACT

The generally unsaturated residual soils segment located above the groundwater table possess negative pore-water pressures. This amount of water content and resulting matric suction is an important geotechnical relationship for the unsaturated residual soil. This paper describes a field study that examined the water content and matric suction in the unsaturated weathered residual soil over one of the commonly found soil/rock types constituting the tropical Malaysian terrain i.e. residual soil over sandstones at various weathering grades. The soil-water characteristic curve (SWCC) was found to be characterized by two distinct curves, a wetting (sorption) curve and a drying (desorption) curve, each showing distinctive water retention propensity. Higher weathering grades appear to have a higher suction for a given water content.

**Keywords:** unsaturated residual soils, weathered sandstones, weathering grades, matric suction, soil- water characteristics.

## INTRODUCTION

Tropical residual soils that develop from weathering acquire unique physical characteristics related to the type of rocks on which they develop. The most distinctive is the microstructure; resulting from particle size and pore size distributions and soil structure and texture; which has been found to control their physical properties like porosity and permeability. Porosity is one of the factors that control the water holding capacity of any soil and, hence, water saturation that impacts on their geotechnical properties.

Sandstones have a lower porosity due to induration and cementation that decreases the sizes of their interstices. Sandstones cemented with silica and calcareous matter are reported to have a porosity of less than 1%, those with clayey matter have a higher porosity and poorly cemented sandstone about 35% (Karanth 1989). The weathering of exposed sandstones results in the dissolution of cements and the breakdown of the primary minerals to new **secondary** minerals more stable in the surface environment. The abundant supply of fresh meteoric water and relatively unrestricted transport causes dissolved constituents to be carried away from the site of dissolution. This destabilizes the framework in which the grains are held in the sandstone that is transformed into residual regolith or soils causes a net gain in porosity. The chemical weathering in humid regions is intensified by the heavy rainfall, lush vegetation and accompanying voluminous production of organic and inorganic acids.

The extent to which the breakdown of the sandstone has occurred is given by the grades of weathering which serve as an index of weathering. The microstructure resulting from particle size and pore size distributions and soil structure and texture controlling their physical properties like porosity and permeability vary with the various grades of weathering. The microstructure changes with depth as a result of the changes in the grades of weathering thus affect the water saturation capacity.

Slopes are held in place by cohesion, frictional and suction strengths. In partially saturated soils it is the water that gives it the strength. More exactly, it is the negative or unsaturated pore-water or suction pressure that holds the soil together. The frictional component is the same regardless of the pore-water pressure condition. The negative pore-water pressure is the mechanism that prevents the landslides along slopes. If a slope gets too wet (even if it is not saturated) it may lose strength provided by the suction pressures subjecting it to the risk of failure. The residual soils, as they lie above the water table, form unsaturated soils that exhibit negative pore-water pressures. The resulting residual soil profiles with different weathering grades exposed on slopes or road cuts may have various capacities and degrees of saturation due to varying negative pore-water pressures along the slopes. As a consequence there appears to be a realization that much of the unusual behavior exhibited during laboratory testing is related to a matric suction change in residual soils is due to negative *in situ* pore-water pressures (Fredlund & Rahardjo, 1985, 1993).

A soil-water (moisture) characteristic curve (SWCC) shows the important relationship between water content of a soil to matric suction (Fredlund & Rahardjo, 1993, Ali & Rahardjo 2004). In addition to describing the particular relationship between soil moisture and suction Fredlund & Xing (1994) have proposed that the SWCC can be used for the prediction of engineering properties, such as permeability, in soil in a partly saturated state as studies have shown a relationship between the soil-water characteristic curve of a partly saturated soil and its engineering properties. The SWCC essentially shows the ability of an unsaturated soil to retain water under various matric suctions as the water content dictates the manner by which the permeability, shear strength and volume change of the soil will behave at different matric suctions upon drying and wetting (Fredlund & Rahardjo 1993). It has a similar role as the consolidation curve of a saturated soil that relates void ratio or water content to effective stress.

There is no satisfactory theory for the prediction of the SWCC from basic regolith properties so its shape, affected by the particle size and pore size distribution and soil structure and texture, must be determined experimentally. This paper describes a field study of the soil water characteristics of unsaturated residual soils over weathered sandstone exposed on a slope, which is one the commonly found soil/rock types in Malaysia. The SWCC curves derived for the various grades of weathering as associated with depth are described.

# METHODS

## Field Site

The field site was a slope cut approx. 40 m high along a link road near the Kuala Lumpur International Airport, Sepang, Malaysia. The slope comprised of residual soils over weathered sandstone. The soils were generally yellowish brown in color and consisted mainly of fine sand and silt. Fig. 1 shows a cross section of the slope cut.

The weathering grades along the slope were determined by the commonly used classification of Little (1969).

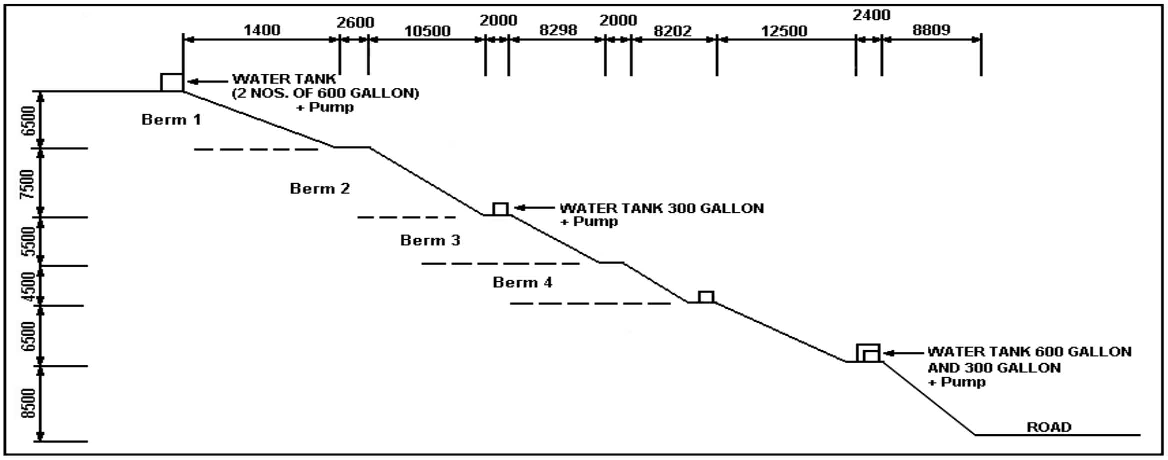

**Figure 1:** Sectional profile of the slope cut

## Field Test Apparatus

The *in situ* field tests were carried out each of the slope berms. A quick draw tensiometer probe designed to measure soil suction in the field was used. It is basically a modified ‘jet filled’ portable tensiometer for rugged field use and is only able to measure suction up to 1 bar (100 kPa). Fig. 2 shows details of the quick draw tensiometer. The tensiometer was applied on each of the cut slope berms to a depth of about 30 cm.

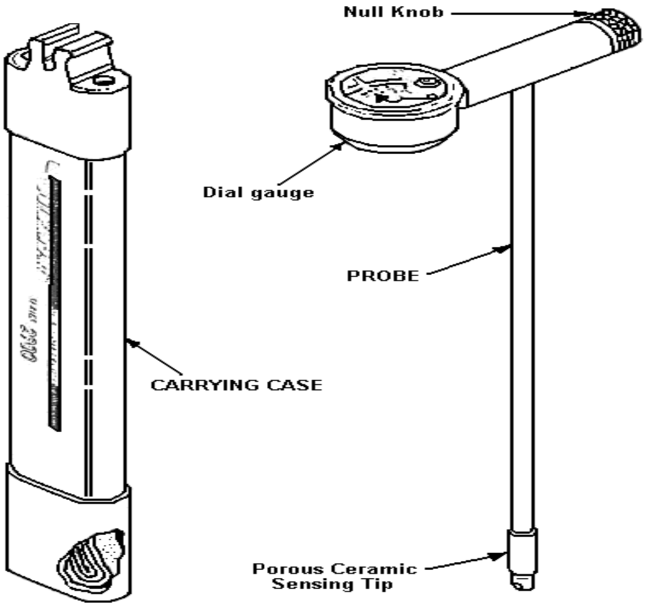

**Figure 2:** Details of quick draw tensiometer probe (Soil Moisture Equipment Corp., USA)

# RESULTS

## The Weathering Grades on the Slope Cut Profile

The following weathering grades were determined in the cut slope profile which a decreasing grade of weathering with depth

Berm 1 – Weathering grade V

Berm 2 – Weathering grade IV

Berm 3 – Intermediate weathering grade of IV and III

Berm 4 – Weathering grade III

## Field Test Results

The in situ field tests were carried out on each of the cut slope berms representing residual soils of weathering grades V to III. The results obtained for the weathering grades at the respective berms shown in Fig. 1 are given in Figs. 3-6. These SWCCs show a wide scatter with a marked hysteresis between the upper and lower envelopes or boundary curves representing the drying (desorption) and wetting (sorption) curves respectively.

The wetting curves are characteristically concave (except for Berm 1). The drying curves, conversely, are found to be convex. The drying curve and wetting curves, therefore, display dissimilar shapes.

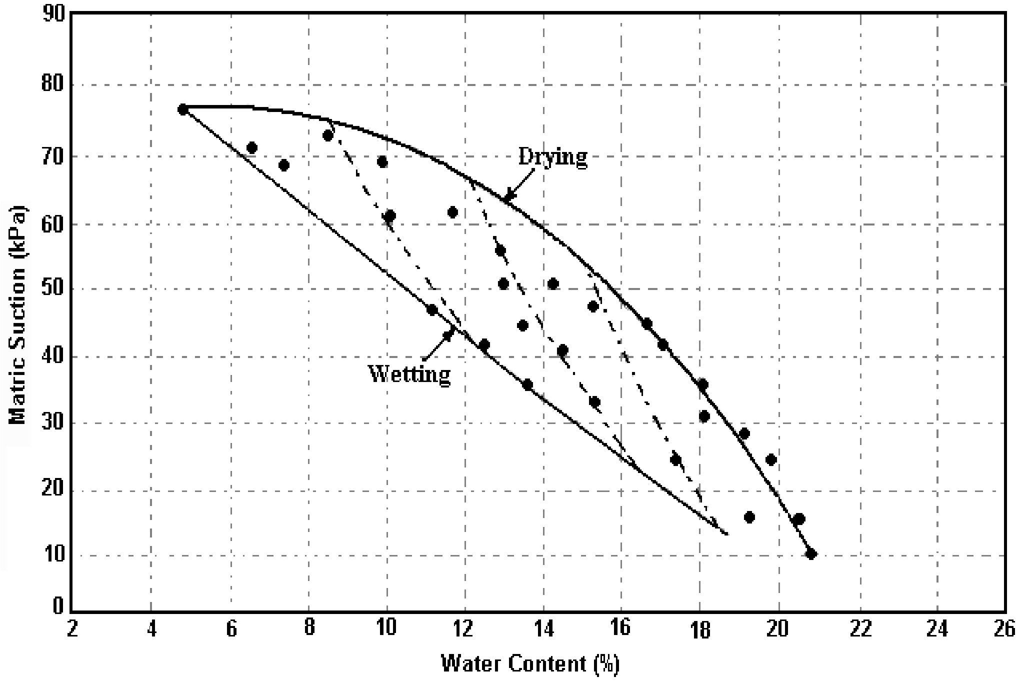

**Figure 3:** Field determined SWCC at weathering grade V (Berm 1)

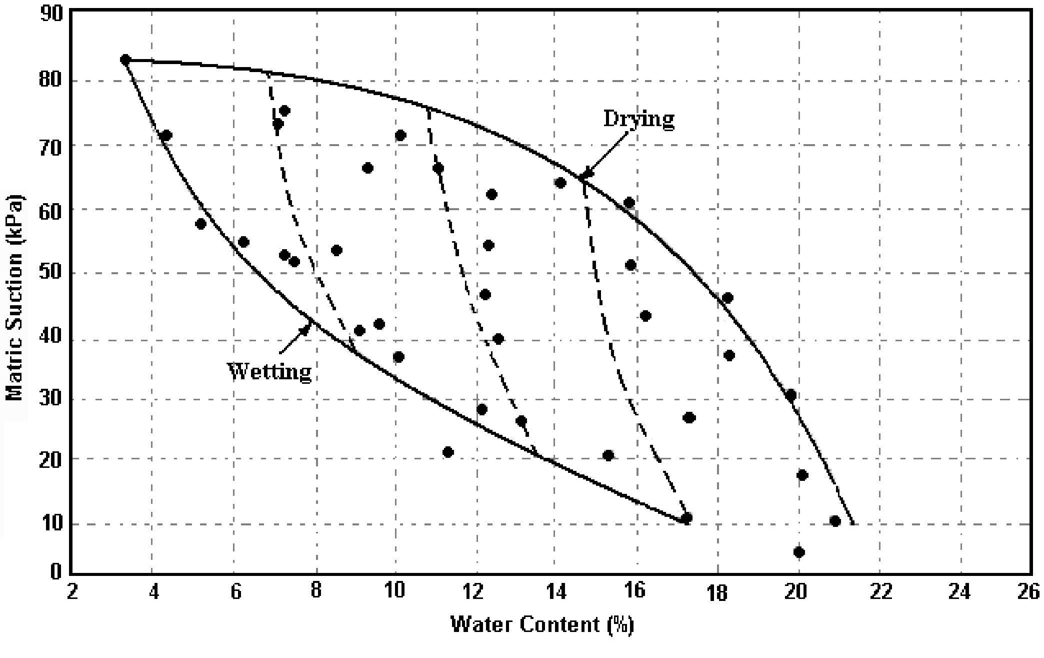

**Figure 4:** Field determined SWCC at weathering grade IV (Berm 2)

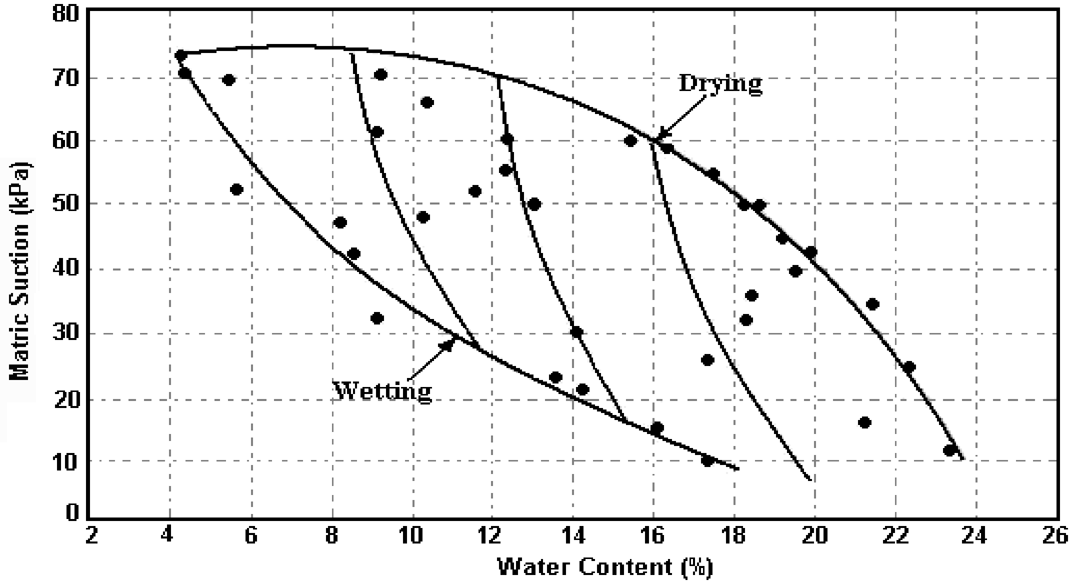

**Figure 5:** Field determined SWCC at intermediate weathering grade between IV and III (Berm 3)

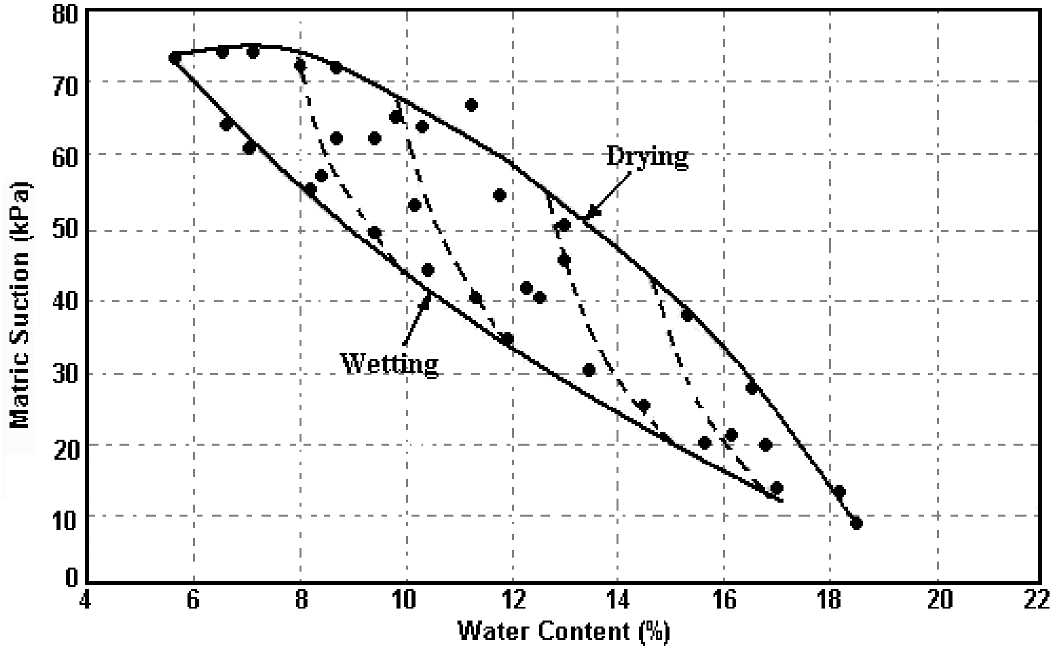

**Figure 6:** Field determined SWCC at weathering grade III (Berm 4)

# DISCUSSION

## Wetting Curves

The characteristically concave (except for Berm 1) wetting curves from the field test show a rapid decrease in suction leveling off at suction below about 20 kPa upon a progressive increment in water content.

The characteristically concave wetting curve from the laboratory tests indicates that there is an initially significant decrease in the soil water content with increasing suction over a lower suction range until the ‘de-saturation’ or air entry point. After this point, the magnitude of decrease in soil water content is less for a corresponding equal range of increment of suction. This is attributed to the draining of water out of the soil pores becoming more and more difficult due to increasing surface tension forces at the contractile layer.

The de-saturation or air entry points for the soils samples with weathering grade V (Berm 1) and weathering grade IV (Berm 2) are approximately at 200 kPa and 192 kPa respectively. The de-saturation points of soils samples with weathering grades IV-III (Berm 3) and grade III (Berm 4) were, however, found to be slightly lower at about 182 kPa and 164 kPa respectively. The lower de-saturation value of soils samples with weathering grades IV-III (Berm 3) and grade III (Berm 4) is attributed to their weathering grades as they have lower degrees of weathering as compared to soils samples with weathering grades V (Berm 1) and IV (Berm 2). The higher degree of weathering translating to a higher amount of fines results in a more compact particle arrangement and a smaller pore size. Soils with smaller pore sizes de-saturate at higher matric suction (Croney and Coleman, 1954).

## Drying Curves

The drying curves, conversely found to be convex, show a steep increase in suction pressure upon the progressive decrease in water content till about 60 kPa but there after, at high suction values, tend to exhibit a plateau. The drying curve and wetting curves appear to show a tendency to converge at low suction values.

A disparity is seen in the case of drying curves of the various soils samples from the laboratory test. Two curves, namely, soil samples with weathering grades IV (Berm 2) and between IV and III (Berm 3) tend to show a reasonably concave character while two, namely, soil samples with weathering grades V (Berm 1) and III (Berm 4) show a convex trend similar to the drying curves. The concave wetting curves indicates that there is an initially slow increase in the soil water content with increasing suction over a lower suction range until the ‘de-saturation’ or air entry point. After this point, the magnitude of increase in soil water content is lesser for a corresponding equal range of increment of suction. This is attributed to the forcing of water into the soil pores becoming more and more difficult due to the presence of air in the pores. The convex curves wetting curves indicate that the indicates that there is an initially significant increase in the soil water content with increasing suction over a lower suction range until the ‘de-saturation’ or air entry point. After this point, the magnitude of increase in soil water content is less for a corresponding equal range of increment of suction. This is attributed to an initial high surface tension forces absorbing the water after which intake of water into the soil pores becoming more and more difficult due to the presence of air in the pores

## The SWCC between the Weathering Grades

Upon comparison of the SWCCs displayed by various weathering grades in Figs. 3- 6 for field tests it appears that soils of weathering grade V (Berm 1) has higher matric suction at any given water contents along the wetting curve compared to the other curves. This is attributed to the fact that soils of weathering grade V had higher fine contents due to its higher degree of weathering compared with the soils of the lower weathering grades. Additionally, the considerable scatter in the data between the drying and wetting curves is accounted for a follows. A number of intermediate curves can be identified between the drying and wetting curves from these data points which are termed as subsidiary or scanning curves. When the water content increases at a particular suction pressure a new wetting curve path arises but the upper boundary drying curve remains the same except that it terminates at the new deviations of the lower bound wetting.

# CONCLUSIONS

The field measurement shows that the soil water relationship is characterized by two distinct curves, a wetting (sorption) curve and a drying (desorption) curve. The wetting curve is characteristically concave, showing a rapid decrease in suction for higher suction and leveling off at low suction. The drying curve, however, tends to exhibit a plateau at high suction values. The soil water curves show a number of intermediate or scanning curves before joining either the drying or wetting curve. Residual soils of weathered sandstone of high weathering grade appear to have higher suction for a given water content.

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