Determination of Permeability Characteristics and SWCC of an Unsaturated Residual Soils in Sri Lanka

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ABSTRACT: Sri Lankan residual soils are formed by weathering of the metamorphic parent rock. Failure in slopes made of such residual soils frequently occurs due to excessive rainfall. With the rain water infiltration, soil will gradually get into a saturated state loosing the matric suction. Sometimes perched water table could also develop. Therefore, with the rainfall, slopes that are stable in dry periods may be subjected to failure. Soil Water Characteristic Curves (SWCC) and knowledge of variation of permeability in unsaturated soil are essential to model this behavior and to devise a reliable early warning system which is in most demand in the present day context. This research project focuses on the development of the permeability function of an unsaturated residual soil in Sri Lanka. Permeability function for both wetting and drying phases were investigated. The method is based on continuously drying and wetting the soil sample while continuously monitoring the suction gradient and the change in soil mass.

1 INTRODUCTION

Most landslides in Sri Lanka are triggered by excessive rainfall. Rain triggered failures in slopes which are made from residual soils is a major geotechnical hazard in Sri Lanka. Residual soils are the weathered product of the parent rock that remain at the initial place. In Sri Lanka, mostly the parent rock is metamorphic. During the dry season ground water table is low and upper part of the slope is unsaturated. The safety margins of these slopes are high during the periods of dry weather. With the rain water infiltration soil, will gradually get into a saturated state and failures in the slopes are triggered by excessive rainfall.

In soil above the ground water table some voids are filled with air and some remain filled with water. It is called an unsaturated state.

An unsaturated soil has commonly been referred to as a three-phase system. However, it is proposed that an unsaturated soil actually consists of four phases. It is postulated that in addition to the solid, air and water phases, there is the air-water interface that can be referred to as the contractile skin. The most distinctive property of the contractile skin is its ability to exert a tensile pull. It behaves like an elastic membrane under tension throughout the soil structure (Fredlund & Rahardjo, 1993).

In an unsaturated soil water flows only through the pore space filled with water. Pores filled with air are not conductive to water. Part of the water that enters the soil will get stored increasing the water content. The storage of water is related to the matric suction. This can be characterized by the Soil Water Characteristic curves (SWCC). The water coefficient of permeability depends strongly on matric suction. Therefore, SWCC and water coefficient of permeability are the most important hydraulic properties for unsaturated soils.

2 SUCTION MEASUREMENT

The matric suction in a soil is defined as;

$$S = U_a - U_w \quad (1)$$

Where u_a is the pore air pressure (equal to the atmospheric) and u_w is the pore water pressure.

There are many methods to measure matric suction. They are; axis-translation, tensiometer, filter paper (Fredlund & Rahardjo, 1993).

A miniature tensiometer was developed at Department of Civil Engineering, Kasetsart University, Thailand. It consists of Micro Electro Mechanical Systems (MEMs) pressure sensor, 1BAR High-Air-Entry porous ceramic and transparent acrylic tube as shown in the Figure 1 (Jotisankasa et al, 2010).

Fig.1 Miniature KU tensiometer sensor

This device can transfer tensile stress between soil water and pressure sensor. To achieve this condition fully saturation of the device is required. This is achieved by evacuating air from different parts of the device using a vacuum pump in a water-filled reservoir.

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KU tensiometers can also be used as piezometer to monitor positive pore water pressure (Jotisankasa, 2010).

3 ESTABLISHMENT OF SWCC USING KU TENSIOMETER

The Soil-Water Characteristic Curve (SWCC) presents the relationship between matric suction and the state of soil wetness. The soil wetness can be expressed as degree of saturation (S_r), gravimetric water content (w) or volumetric water content (θ), which are related by the equation 2;

$$\theta = \frac{V_W}{V} = \frac{w.G_s}{1+e} = \frac{Sr.e}{1+e} = \frac{w.\gamma_{dry}}{\gamma_w} \quad (2)$$

SWCC is required for the analysis of rainfall infiltration into the slope and to predict unsaturated shear strength and permeability characteristics. Also, SWCC is used to estimate the amount of rainfall required to reduce the matric suction to zero or fully saturate the slope.

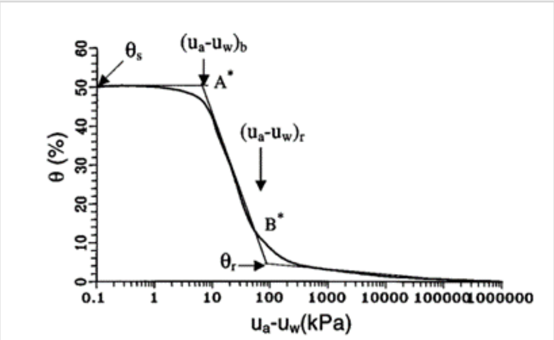

Fig.2 Soil Water Characteristic Curve

Figure 2 shows SWCC with two characteristic points A* and B*. Point A* corresponds to the air-entry value and B* corresponds to the residual water content (Fredlund & Rahardjo,1993).

In this study, SWCC of undisturbed samples were determined using miniature KU tensiometer sensor within the limits of 100kPa. There are two main testing methods; point wise measurement and continuous measurement (Jotisankasa et al, 2010).

3.1 Point-wise measurement

Sample is gradually wetted and dried and their suctions were monitored during each stage incrementally. A minimum curing period of about 2-3 days between each increment was allowed for equilibration of the suction throughout the sample.

3.2 Continuous measurement

Sample is gradually wetted and dried and their suctions were monitored continuously. The sample weight was also continuously measured.

4 DETERMINAION OF THE PERMEABILITY FUNCTION

The SWCC measurement method can also be used to determine the permeability function. The values of suction at three locations can be used to calculate the hydraulic gradient, i, given by equation 3;

$$i = \frac{d(z - s/\gamma_w)}{dz} \quad (3)$$

Where z is the elevation head of each tensiometer relative to the base of sample, s is matric suction, and γ_w the unit weight of water. It was found that hydraulic gradient, i, calculated over only the upper and middle pore pressure measurement gives a better result of k-function than if calculated over three measurements.

The plot of change in soil mass with time can be used to calculate the flux or discharge velocity, v, at any particular time is given by equation 4;

$$v = \frac{dV_w}{A.dt} \quad (4)$$

Where dV_w is the change of volume of water in soil sample which can be calculated from change in soil mass during test, A is the cross-section area of sample, and dt is the elapsed time.

The value of permeability at any suction and volumetric water content can then be calculated by equation 5;(Jotisankasa et al, 2010).

$$k = {}^{v}/_{i} \quad (5)$$

5 EXPERIMENTAL STUDIES

Experiments were conducted to establish; SWCC and permeability functions of an unsaturated residual soils of Sri Lanka using an undisturbed soil samples obtained from the site of the rectified slope at Welipenna in the Southern Expressway.

Initially, the basic properties of the soil, such as; particle size distribution, Atterberg limits, specific gravity etc. were determined. Then experiment was conducted to determine permeability function and SWCC.

5.1 Classification of the soil

Particle size distribution obtained using the wet sieving technique is presented in Figure 3. Soil sample is made of; Gravel 16%, Sand 64%, Silt 16% and Clay 4%. Atterberg limit tests indicated that the fines are non-plastic. Therefore, soil is classified as Silty Sand (SM) according to the Unified Soil Classification System.

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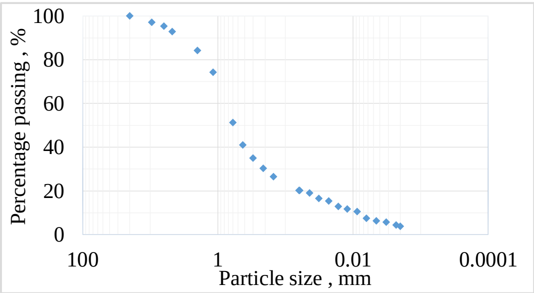

Fig. 3 Particle size distribution

5.2 *Tests to establish SWCC and permeability function by using continuous measurement.*

Tests were conducted both on the drying path and wetting path with continuous measurements. For drying test an undisturbed sample was taken and initially it was saturated. Thereafter KU tensiometers were installed at different heights on different plan locations (Figure 4). The rate of movement of water is very small and was measured through the weight loss as determined by an electronic balance.

In the wetting test the top surface of sample is continuously wetted by using a burette as shown in Figure 4. Suction was monitored continuously at three locations and weight was also continuously measured.

Fig.4 Testing procedure for continuous Measurements

Matric suction variation with time was plotted for both drying and wetting path (Figure 5 and 7).

To determine SWCC, volumetric water content was calculated by using equation 2 and it was plotted against matric suction. SWCC for both drying and wetting path are presented in Figures 6 and 8.

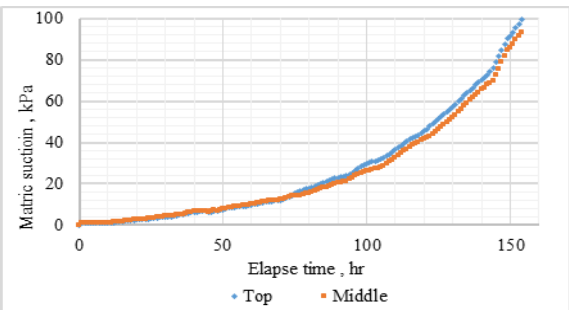

Fig.5 Matric suction variation with time for drying path

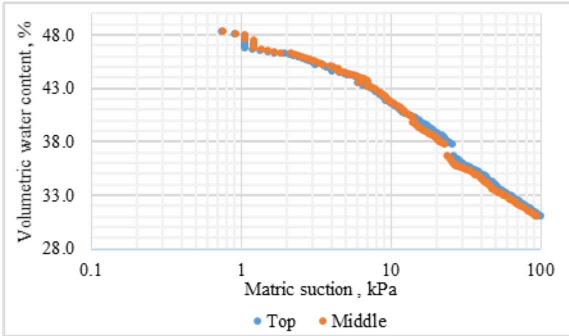

Fig. 6 SWCC for drying path

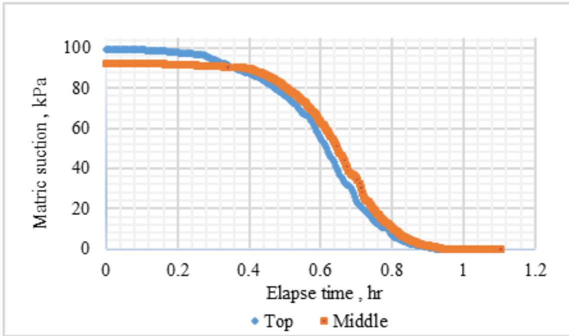

Fig.7 Matric suction variation with time for wetting path

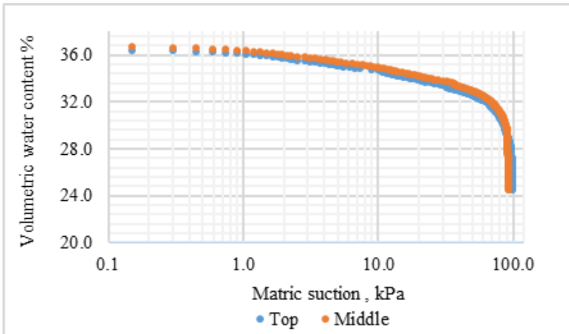

Fig. 8 SWCC for wetting path

The hydraulic gradient was estimated using Equation 3 for both drying and wetting test. The results are presented in Figures 9 & 10.

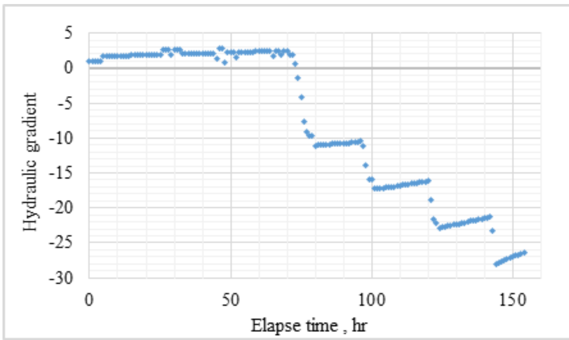

Fig. 9 Hydraulic gradient Vs time for drying path

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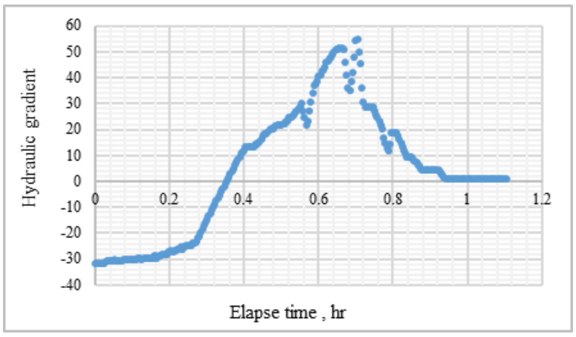

Fig. 10 Hydraulic gradient Vs time for wetting path

The hydraulic conductivity was estimated using Equation 5. Results are presented in Figure 11 & 12. Similar results are reported in Jotisankasa et al, 2010. The saturated permeability of the soil is 8.69×10^{-7} m/s.

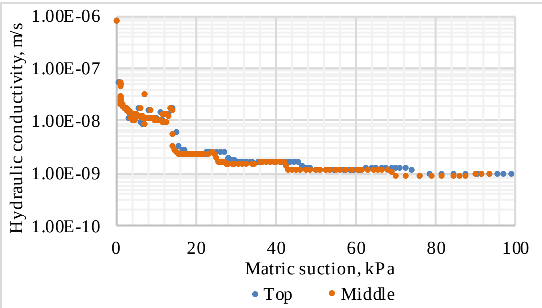

Fig. 11 Hydraulic conductivity variation with matric suction for drying path

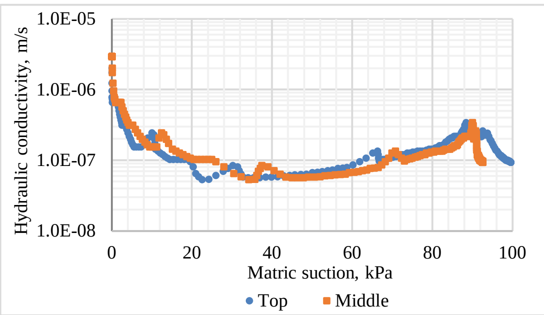

Fig. 12 Hydraulic conductivity variation with matric suction for wetting path

5.3 *Tests to establish SWCC by using point-wise measurement.*

This method involves testing of especially prepared samples at different moisture contents to obtain the SWCC. To establish the wetting curve, water is added to soil sample and kept for curing to equalize the suction throughout the sample, which was carefully wrapped to prevent evaporation. After curing the sample, matric suction was measured using KU tensiometers and water content of the sample was determined (Figure 13).

Volumetric water content variation with the matric suction were plotted to obtained SWCC for wetting path (Figure 14)

Fig. 13 Testing procedure for point-wise measurement

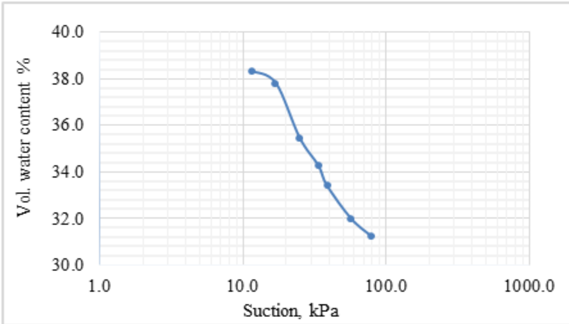

Fig. 14 Results during wetting path of point-wise SWCC measurements.

6 CONCLUSION

Slope failures in Sri Lanka are triggered by excessive rainfall. With the establishment of the SWCC and permeability function of the different residual soils in Sri Lanka, the process of rainfall infiltration and loss of matric suction can be modeled to a reasonable accuracy and it will help to establish threshold values of rainfall that could lead to failure in a given slopes. This research presents the results of a study to establish SWCC and Permeability functions for Sri Lankan residual soils.

7 REFERENCES

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