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Soil-Suction Measurements Using the Filter Paper Method to Evaluate Swelling Potential

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Abstract: ***Soil suction is directly related to the free energy of the pore-water in a soil, thus it can be accurately used to qualitatively classify the relative swelling potential of expansive soils. The relationship between the affinity of soil to retain water and suction can be determined based on the filter paper technique of total suction measurement. The advantage of using filter paper to quantify soil suction is its potential to provide a wide range of reliable accurate information easily and cheaply. This paper evaluates total potential suction value by controlling the variables for measurement of the water content of filter paper that was in direct contact with soil disks in an easily installed sensing chamber for seven days. After the filter papers had reached suction equilibrium with the surrounding soil, the moisture content was carefully measured and soil suction values were related to a total-suction value through calibration curves obtained from an established correlation for equilibrium filter papers over salt solution of known total suction. The obtained values of total suction were thereafter used to estimate the expansiveness of soils. According to the experimental data of the suction test, the soil in consideration falls in high expansive potential.***

Keywords: Soil suction, matric suction, osmotic suction, soil suction, filter paper, calibration, suction measurement, expansive potential.

Introduction

Soil suction is a microscopic property that indicates the intensity or free energy level (force per unit area) of water that the soil attracts (Fredlund and Rahardjo, 1993, Bulut et al., 2001, Ridley et al., 2003, Rao and Shivananda, 2005 and Sreedeep and Singh, 2006). Soil suction comprises two components namely osmotic and matric (capillary) suctions.

Matric suction represents capillary phenomenon due to capillary nature, texture and adsorptive forces of unsaturated soils, and it varies with changes in moisture content of the soils. The osmotic suction is a result of the presence of dissolved salts in the pore fluid. The sum of the matric suction and osmotic suction equals to total suction. The relationship between the total suction and the osmotic and matric suctions under isothermal conditions is as shown in the following equation (Chen, 1998).

$$\text{total suction } h_t = h_0 + h_m \text{------------------------(1)}$$

(assuming gravitational and external pressure effects are negligible)

where h_o is the osmotic suction and

$h_m = (h_a - h_w)$ is the matric suction

h_a = pore-air pressure

h_w = pore-water pressure

The simple and cheap favoured method to conduct the suction test over a wide range of suction is by the use of filter paper in accordance with the ASTM D 5298. This involves collecting the undisturbed samples from ground profiles and taking them to the laboratory for testing. The samples are split across their diameters to form a series of soil disks, then the filter paper is inserted between the discs and sealed within an easily installed sensing chamber and stored for a at least seven days. After the filter papers have reached suction equilibrium with the surrounding soil, the moisture content is carefully measured and soil suction values are related to a total-suction value through calibration curves obtained from an established correlation for equilibrium filter papers over salt solution of known total suction.

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Figures 1 and 2 show the wetting curve constructed using NaCl salt solution and Schleicher & Schuell No. 589-WH filter papers. The curve has two regimes; the upper segment represents moisture retained in the soil by surface adsorption processes, and the lower part represents moisture retained by surface tension and capirally forces between particles (ASTM D 5298). The suction is calculated either in *log kPa* ($\log_{10}|suction\ in\ kPa|$) unit system (Figure 1) or in *pF* ($\log_{10}|suction\ in\ cm\ of\ water|$) units (Figure 2). The two systems are approximately related by suction in *log kPa* = *suction in pF*-1 (Bulut et al., 2001). From the Figures 1 and 2 the relationships between suction in *log kPa* as well as *pF* are summarized in Table 1. Suction is zero in soils whose moisture is in balance with the free water and greater than zero in soils above the ground water level. The maximum value of suction is reached at about pF = 7 corresponding to clay dried in an oven at 110°C (Trevisan, 1988).

Once the suction had been got hold of, the swell can be readily calculated. Brackley, 1980 proposed the following empirical equation to calculate the swelling pressure based on suction values and effective overburden stress at the depth in question:

$$\text{Swell \%} = \frac{PI - 10\log_{10}\frac{S}{P}}{10} \quad \text{-----------------------(2)}$$

where S is the soil suction at the centre of the layer, PI is the plasticity index and

P is the overburden plus foundation stress at that depth

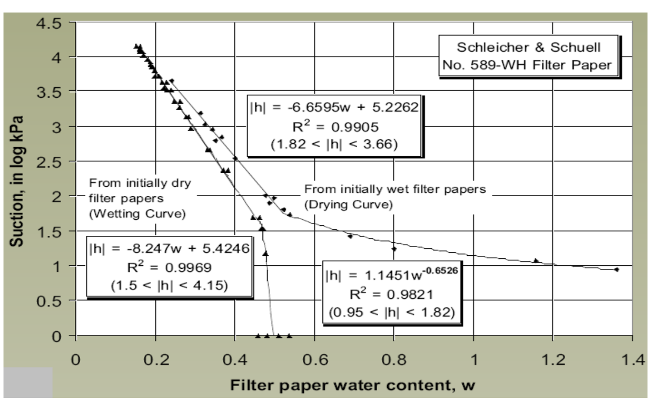

Figure 1: Filter paper drying calibration curve along with wetting suction curve for determination of suction in log kPa (Bulut et al., 2001).

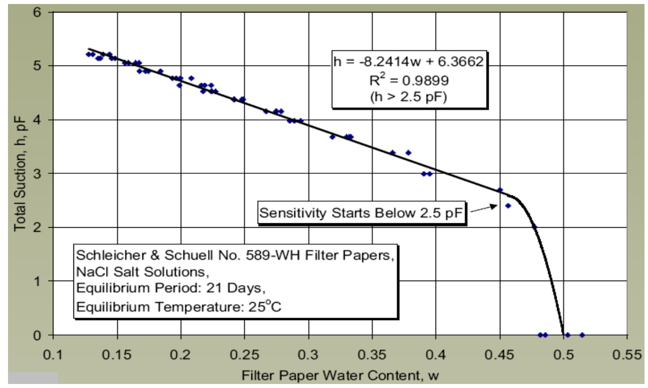

Figure 2: Filter paper wetting calibration curve for determination of suction in pF (Bulut et al., 2001).

Table 1: Filter paper calibration relationships.

Filter paper	*log kPa* ($\log_{10}(\|suction\ in\ kPa\|)$)	*pF* ($\log_{10}(\|suction\ in\ cm\ of\ water\|)$)
Schneider & Schuell No. 589-WH	$\|h\| = 5.4246 - 8.247w$ $R^2 = 0.9969$ $(1.5 < \|h\| < 4.15)$	$\|h\| = 6.3662 - 8.2414w$ $R^2 = 0.9899$ $(h > 2.5pF)$

Suction and moisture content correspond to one another and are interdependent, thus a change in one will be associated with the change in the other. The increase in moisture content is usually associated with the decrease in suction toward a value of zero. On the other hand, the corollary of decrease in soil moisture is the increase in the suction of the soil. Conversely, soil volume decreases as the soil suction increases, and soil volume increases as soil suction decreases. Likewise, the amount of moisture content in the soil depends on the stress state to which the soil is subjected. An increase in suction will remove the absorbed water from the soils. When the moisture content of the clay soils is reduced the clay shrinks causing downward movement. On the other hand, decrease in suction triggers the entry of water molecules between the clay layers, thus inducing the swelling of the soils.

Most pronounced changes in suction are distinct during the extreme seasons. Suction in soil decreases toward a value of zero in response to infiltration of rainfall. The removal of water from the ground by evaporation during spells of extremely hot dry weather is associated with increase in suction.

Materials

The soil disks used in this experiment were prepared from expansive retrieved from open pits dug during a dry (September) and a wet (April) periods of the year near Tumbi Catholic Church in Kibaha Town, Coast Region, Tanzania (time of retrieval). The area is rich in significant amount of clay soil which is characterised by the presence of high active minerals of montmorillonite (Lucian, 2009). Most soils that belong to the family of montmorillonite exhibit a high degree of expansion when wet and shrinkage when dry. Usually, the degree of expansiveness is proportional to the amount of montmorillonite or other expansive clay minerals present in the soil.

Experimental Procedure and Results

The soil suctions of specimens were determined by using ASTM Standard Test Method for Measurement of soil potential (suction) using filter paper ASTM 5298. Cylindrical specimens of approximately 70 mm diameter each were trimmed from undisturbed samples and the filter papers were placed between the specimens (in intimate contact with the top and bottom surface of the specimens). The samples were sealed in airtight containers, stored in a temperature-stabilized room for 7 days for establishment of moisture equilibrium. Within these sealed in airtight containers the relative humidity reached equilibrium with the pore depending on the total suction in the samples. Thereafter, the water contents of the filters were careful measured to the nearest 0.0001 g precision (Appendix 7). The measured water content values were averaged and the average values were used in the analysis. Suction values of specimens were obtained from calibration relationship of the filter paper Schleicher & Schuell No. 589 H (Figure 1). Table 2 presents suctions and a few physical properties for the series of specimens from two pits.

As it is indicated in Table 2, the matric suctions decreased with increase in depth below ground level concordant with the dry season of sample collection. The results indicate that both sites have lower moisture contents typically ranging between 11.54% and 17.44% and high suction values ranging from 29.7 MPa to 9.7 MPa signifying high swelling potential upon wetting. Furthermore, higher suction and lower moisture content indicate an upward moisture migration caused by evaporation

Expansive Potential using suction values

Using matric suction values, plasticity index and the estimated overburden pressure, equation (3) is employed to estimate the expansiveness (Brackley, 1980) as follows:

$$\text{Swell \%} = \frac{PI - 10\log_{10}\frac{S}{P}}{10} \text{---------------(3)}$$

Where S is the soil suction at the centre of the layer

P is the overburden plus foundation stress at that depth

The first step is to work out the earth pressure, then the stress from the building and the two add up to total stress. For soil pressure for RC 4 at 1 m depth, with suction value of 29.7 MPa, plasticity index (PI) of 54%, vertical pressure under which swell takes place was first estimated from the bulk density and expected load from the light weight building. Given the bulk density of the soil as 2150 kg/m^3 (2150*9.81*1.0=21kPa), the effective unit weigh (γ') of the soil is 21 – 9.81= 11 kPa.

Stress from a typical lightweight building in the study area constitutes mainly that from the foundation and from the walls. Load from foundation is estimated to be 4 kN (0.6 m * 0.25 m * 1.0 m * 24 kN/m^3). Load from the block wall of 0.23 m thickness is 26 kN/m (0.23 m * 1.0 m * 5 m * 23 kN/m^3). Thus the total load from the structure sums up to 30 kN (26 kN + 4 kN) and gives stress equal to 50 kPa (30/0.6 kPa). The total stress therefore is 61 kPa (50 kPa + 11 kPa)

$$\text{Swell \%} = \frac{54 - 10\log_{10}\frac{29710}{61}}{10} = 2.7\% \text{----------(4)}$$

Subtracting 1.0 m as foundation depth from a 3.0 clay layer measured from ground level, the anticipated heave of the remaining 2.0 layer is 2.7% * 2000= 54 mm. According to the MoW (1999) guidelines, this value falls in the high expansive potential when wet.

Suction variation with depth

Table 3 and Figure 3 indicate the variation of suction with depth. Significant suction decreases during the rainy period and suction increases throughout the no-rain period are found within 2.0 m, and the changes below 2.0 m are essentially negligible for most pits. On average, changes in suction during the rainy period occurred faster than the changes during the dry period down to the depth of 2.0 m. For both periods, the maximum variations in suction took place near the ground surface, where the soil has a high potential to swell. The trend of the results illustrates the accuracy that can be achieved by using the filter paper measurement method to determine the suction.

Conclusions

In this experiment the filter paper has been used to estimate the soil suction values for use in the calculation of the expansive potential. The results show that the total suctions decrease with increase in depth below ground level concordant with the seasons of sample collection. The dry period (month of September) was found to have the highest soil suctions in the soil near the ground surface while the wet period (moth of April) had lowest soil suctions near ground surface. For both periods, suction variations are vivid within 2.0 m, and the changes below 2.0 m are essentially negligible for most pits. The suctions increased during dry periods and decreased during wet periods. Both sites have high suction values ranging from 29.7 MPa to 9.7 MPa signifying high swelling potential upon wetting. Furthermore, higher suction and lower moisture content indicate an upward moisture migration caused by evaporation.

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References

1. ASTM D 5298- 94 (1994). Standard test method for measurement of soil potential (suction) using filter paper. Designation D 5298-94, American Society for Testing Materials, West Conshohocken, PA.

2. Brackley, J. A. (1980). Prediction of soil heave from suction measurements. Proceedings of the 7th Regional Conference for Africa on Soil Mechanics and Foundation Engineering, Accra, vol. 1, pp. 159 – 166.

3. Bulut, R., Lytton, R.L. and Wray, W.K. (2001). Soil suction measurements by Filter Paper, in Expansive Clay Soils and Vegetative Influence on Shallow Foundations. American Society of Civil Engineers Geotechnical Special Publication No. 115 (ed. C. Vipulanandan, M. B. Addison and M. Hasen), Reston, VA, pp. 243-261.

4. Chen, F. H. (1988). Foundations on expansive soils, Elsevier Science Publishers B. V.

5. Fredlund, D.G. and Rahardjo, H. (1993). Soil mechanics for unsaturated soils. John Wiley and Sons, Inc., New York of soils.

6. Lucian, C. (2009), “Spatial Variability of Expansive Soil Properties at Different Scale within Kibaha, Tanzania”, The Global Journal of Agricultural Sciences, Vol. 8, No.1, pp. 95-100

7. MoW (1999). Pavement and materials design manual, Tanzania.

8. Rao, S. M. and Shivananda, P. (2005). Role of osmotic in swelling of salt-amended clays. Canadanian Geoechnical Journal, vol. 42, pp. 307-315.

9. Ridley, A.M., Dineen K., Burland, J.B. and Vaughan, P. R. (2003). Soil matrix suction: some examples of its measurement and application in geotechnical engineering. Geotechnique 53, No.2, pp. 241-254.

10. Sreedeep, S. and Singh, D. N. (2006). Methodology for determination of osmotic suction of soils. Journal of Geotechnical and Geological Engineering, Springer Netherlands, vol. 24, No. 5, pp. 1469-1479.

11. Trevisan, S. J. (1988). Suggestions for a site investigation manual in active clay. Proceedings of the 6th International Conference on Expansive Soils, New Delhi, India, pp. 337–342.

Table 2: Soil suction results.

Pit No.	Depth (m)	w_n (%)	Suction			Clay % (<2μm)	PI (%)	Activity A_c	Bulk density (kg/m^3)
			pF	log kPa	MPa				
A	1	11.54	5.41	4.47	29.7	29	54	1.86	2150
	2	13.65	5.24	4.30	19.9	27	34	1.26	2135
	3	12.27	5.35	4.41	25.9	23	32	1.39	2126
B	1	11.7	5.40	4.45	28.4	27	30	1.11	1966
	2	17.44	4.93	3.99	9.7	25	27	1.10	2085
	3	15.26	5.11	4.17	14.6	22	26	1.18	2130

Table 3: Variation of total soil suction with depth.

Depth (m)	Total soil suction in pF											
	Sample 02		Sample 07		Sample 12		Sample 19		Sample 20		Sample 22	
Month	Sept.	April	Sept.	April	Sept.	April	Sept.	April	Sept.	April	Sept.	April
0.3	5.394	4.759	5.550	4.462	5.418	4.495	5.287	4.347	5.006	4.133	5.006	4.133
0.5	5.344	4.982	5.427	4.545	5.320	4.636	5.278	4.619	4.133	4.141	4.133	4.141
1.0	5.212	4.916	5.353	4.784	5.171	4.858	5.081	4.743	4.611	4.462	4.611	4.462
1.5	5.171	5.122	5.006	4.726	4.924	4.809	5.072	4.891	4.462	4.512	4.462	4.512
2.0	5.039	5.031	4.866	4.718	4.825	4.734	4.940	4.866	4.512	4.504	4.512	4.504
2.5	5.064	5.015	4.767	4.644	4.842	4.677	4.784	4.693	4.504	4.520	4.504	4.520
3.0	5.081	5.023	4.726	4.627	4.833	4.718	4.743	4.644	4.520	4.512	4.520	4.512

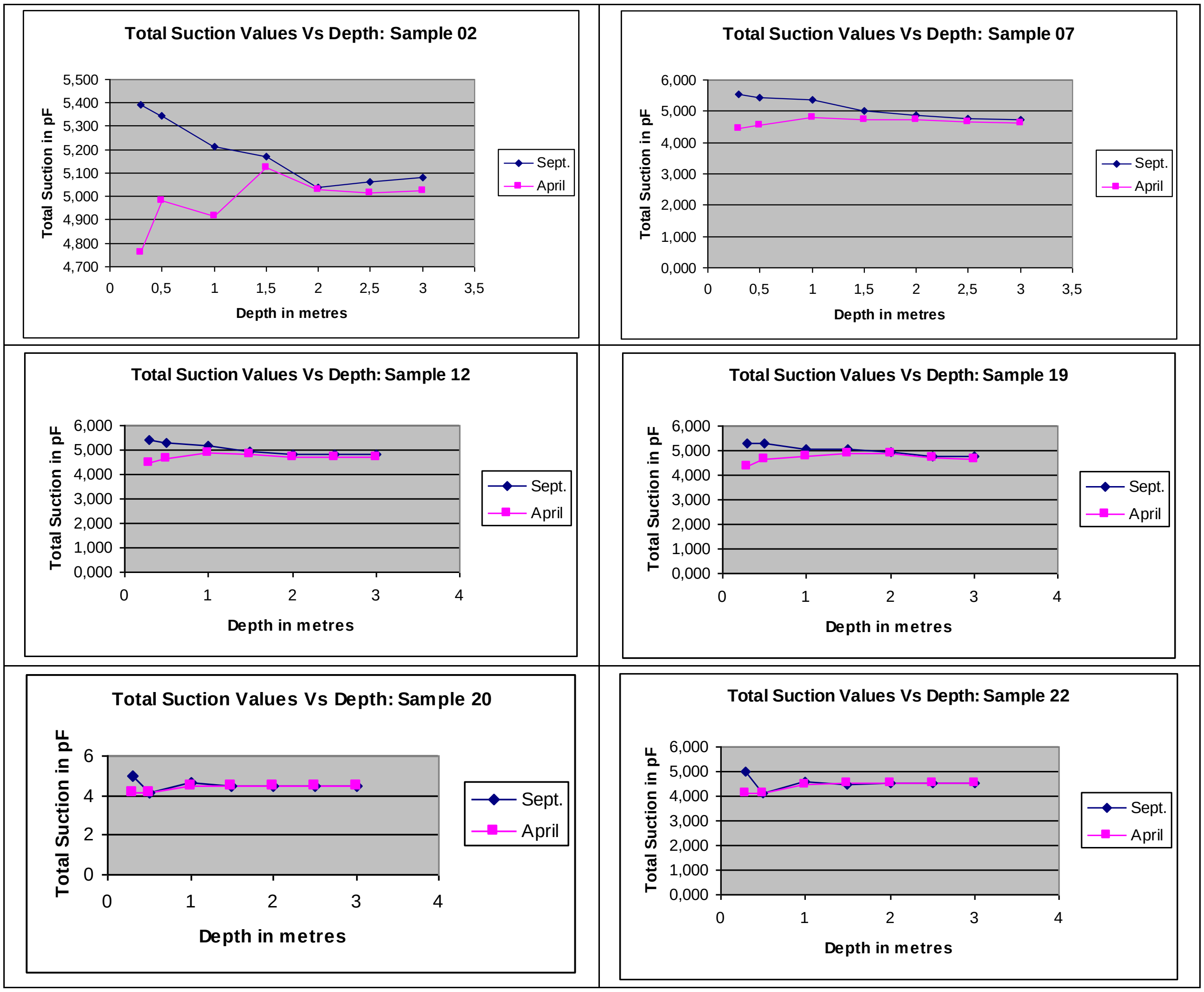

Figure 3: Suction profile with depth to locate the active zone.