TOTAL AND MATRIC SUCTION MEASUREMENT OF UNSATURATED SOILS IN BAGHDAD REGION BY FILTER PAPER METHOD

Mohammed Y. Fattah[(1)] **Asma Y. Yahya**[(2)] **Balqees A. Ahmed** [(2)]

1) **Building and Construction Engineering Dept., University of Technoilogy, Baghdad, Iraq.**
2) **Civil Engineering Dept., College of Engineering, University of Baghdad, Iraq.**

ABSTACT

Soil suction is one of the most important parameters describing the moisture condition of unsaturated soils. The measurement of soil suction is crucial for applying the theories of the engineering behavior of unsaturated soils. The filter paper method is one of the soil suction measurement techniques

In this paper, five soil samples were collected from five sites within Baghdad city – al-Rasafa region. These soils have different properties and they were prepared at different degrees of saturation. For each sample, the total and matric suction were measured by the filter paper method at different degrees of saturation. Then correlations were made between the soil properties and the total and matric suction.

It was concluded that the suction increases with decrease of the degree of saturation. The relationships between the total and matric suction and the filter paper water content are approximately linear and indicate decrease of suction with increase of the filter paper water content. The total and matric suction increase with the decrease of the soil shear strength.

الخلاصة:

ان مص التربة هي واحدة من اهم المعاملات المستخدمة لوصف المحتوى المائي للترب الغير مشبعة. ان قياس المص للتربة مهم لتطبيق نظريات التصرف الهندسي للترب الغير مشبعة. ان طريقة ورق الترشيح هي تقنية لقياس المص للتربة.

في هذا البحث، تم جمع خمس نماذج لخمس مواقع في مدينة بغداد- في منطقة الرصافة. هذه الترب لها خواص مختلفة وقد تم تحضيرها بدرجات تشبع مختلفة . لكل نموذج تم قياس السحب الكلي (total suction) و (matric suction) بدرجات تشبع مختلفة. تم الحصول على علاقات تربط خواص التربة مع السحب للتربة (total and matric suction).

لقد تم استنتاج ان السحب يزداد بنقصان درجة التشبع. ان العلاقة بين السحب (total and matric suction) والمحتوى المائي لورق الترشيح تقريبا علاقة خطية وتشير الى نقصان السحب بزيادة المحتوى المائي لورق الترشيح. ان السحب يزداد عند نقصان مقاومة القص للتربة.

KEYWORDS: Total suction, matric suction, filter paper, unsaturated soil.

INTRODUCTION

The filter paper method is an inexpensive and relatively simple laboratory test method, at which both total and matric suction measurements are possible. With a reliable soil suction measurement technique, the initial and final soil suction profiles can be obtained from samples taken at convenient depth intervals. The change in suction with seasonal moisture movement is important information for many engineering applications.

This paper evaluates both the total and matric suctions for samples taken from five sites in Baghdad city within al-Rasafa region. These soils have different properties and they were prepared at different degrees of saturation. The aim of this paper is to determine relationships between the total and matric suctions and soil properties like, degree of saturation, liquid limit, plasticity index and unconfined compressive strength.

A BRIEF HISTORICAL BACKGROUND

There are many techniques and instruments to measure soil suction in the fields of soil science and engineering. Most limitations with regard to the range of measured suction, equilibration times, and cost. Therefore, there is a need for a method which can cover the practical suction range, and could be adopted as a basis for routine testing, and is inexpensive. One of those soil suction measurement techniques is the filter paper method, which was evolved in Europe in the 1920s and came to the United States in 1937 with Gardner (1937). Since then, the filter paper method has been used and investigated by numerous researchers (Fawcett and Collis-George 1967; McQueen and Miller 1968; Al-Khafaf and Hanks 1974; McKeen 1980; Hamblin 1981; Chandler and Guierrez 1986; Houston et al. 1994; Swarbrick 1995), who have tackled different aspects of the filter paper method.

SOIL SUCTION CONCEPT

Many engineering-related problems are associated with partially saturated soils where the void spaces between particles are partly filled with air and partly with water. This leads to negative pore water pressures (or suctions), which greatly influences the controlling stress regime. The accurate measurement and interpretation of soil suction is thus vital to understanding the behaviour of unsaturated soils. However, magnitudes of suction can vary enormously (between 0 and 1 GPa) and the instruments and measurement techniques are usable over only specific suction ranges. (Murray and Sivakumar, 2010).

In general, porous materials have a fundamental ability to attract and retain water. The existence of this fundamental property in soils is described in engineering terms as suction, negative stress in the pore water. In engineering practice, soil suction is composed of two components: matric and osmotic suction (Fredlund and Rahardjo 1993). The sum of matric and osmotic suction is called total suction. Matric suction comes from the capillarity, texture, and surface adsorptive forces of the soil. Osmotic suction arises from the dissolved salts contained in the soil water. This relationship can be formed in an equation as follows:

$$h_t + h_m + h_\pi \qquad (1)$$

where h_t = total suction (kPa),
h_m = matric suction (kPa), and
h_π = osmotic suction (kPa).

Total suction can be calculated using Kelvin's equation, which is derived
from the ideal gas law using the principles of thermodynamics and is given as (Fredlund and Rahardjo,1993:

$$h_t = \frac{RT}{V}\ln\left(\frac{P}{P_o}\right) \qquad (2)$$

where h_t = total suction,
R = universal gas constant,
T = absolute temperature,
V = molecular volume of water,
P / P_o = relative humidity,
P = partial pressure of pore water vapor, and
P_o = saturation pressure of water vapor over a flat surface of pure water at the same temperature.

If Eq. (2) is evaluated at a reference temperature of 25°C, the following total suction and relative humidity relationship can be obtained.

$$h_t = 137182.\ln(P/P_o) \qquad (3)$$

THE FILTER PAPER METHOD

The filter paper method has long been used in soil science and engineering practice and it has recently been accepted as an adaptable test method for soil suction measurements because of its advantages over other suction measurement devices. Basically, the filter paper comes to equilibrium with the soil either through vapor (total suction measurement) or liquid (matric suction measurement) flow. At equilibrium, the suction value of the filter paper and the soil will be equal. After equilibrium is established between the filter paper and the soil, the water content of the filter paper disc is measured. Then, by using a filter paper water content versus suction calibration curve, the corresponding suction value is found from the curve.

This is the basic approach suggested by ASTM Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper (ASTM D 5298). In other words, ASTM D 5298 employs a single calibration curve that has been used to infer both total and matric suction measurements. The ASTM D 5298 calibration curve is a combination of both wetting and drying curves.

SOIL TOTAL SUCTION MEASUREMENTS

Glass jars that are between 250 to 500 ml volume size are readily available and can be easily adopted for suction measurements. Glass jars, especially, with 3.5 to 4 inch (8.89 to 10.16 cm) diameter can easily contain the 3 inch (7.62 cm) diameter Shelby tube samples. A testing procedure for total suction measurements using filter papers can be outlined as will be described in the following sections.

EXPERIMENTAL PROGRAM

In this work, five soil samples were collected from five sites within Baghdad city – al-Rasafa region at depth equal to 3.5 m below the ground surface. The water table was 1.2 m below the ground surface. The samples were subjected to testing program which included the following tests:

1. Grain size distribution by sieve analysis and hydrometer.
2. Specific gravity.
3. Atterbegr limits; liquid and plastic limit.
4. Unconfined compression test.

All these tests were carried out according to the American Society for Testing and Materials standards. A summary of the index properties of these soils is shown in **Table 1**.

Table 1: Index properties of the soils.

Site	Liquid Limit LL (%)	Plastic Limit PL (%)	Plasticity Index PI (%)	Specific Gravity Gs	% Clay
Rasafa 1	34	19	15	2.74	66.5
Rasafa 2	45	27	18	2.76	68.3
Rasafa 3	54	27	27	2.78	80.3
Rasafa 4	64	25	39	2.79	82.3
Rasafa 5	73	29	44	2.80	85.3

The grain size distribution of the five samples is shown in **Fig. 1**. The figure shows that all these soils are classified as silty clays.

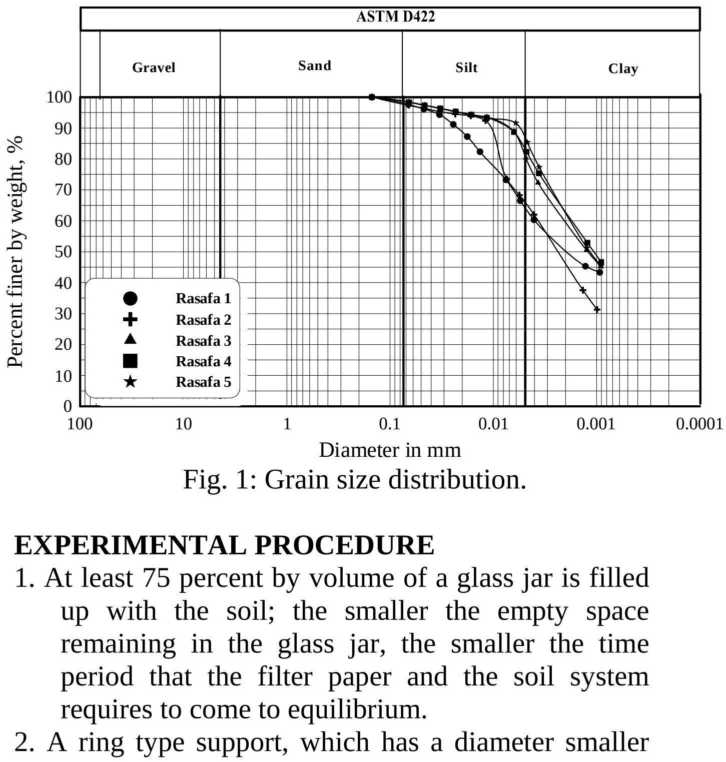


Fig. 1: Grain size distribution.

EXPERIMENTAL PROCEDURE

1. At least 75 percent by volume of a glass jar is filled up with the soil; the smaller the empty space remaining in the glass jar, the smaller the time period that the filter paper and the soil system requires to come to equilibrium.
2. A ring type support, which has a diameter smaller than filter paper diameter and about 1 to 2 cm in height, is put on top of the soil to provide a non-contact system between the filter paper and the

soil. Care must be taken when selecting the support material; materials that can corrode should be avoided, plastic or glass type materials are much better for this job.

3. Two filter papers one on top of the other are inserted on the ring using tweezers. The filter papers should not touch the soil, the inside wall of the jar, and underneath the lid in any way.
4. Then, the glass jar lid is sealed very tightly with plastic tape.
5. Steps 1, 2, 3, and 4 are repeated for every soil sample.
6. After that, the glass jars are put into the ice-chests in a controlled temperature room for equilibrium.

These steps are documented in photographs 1 to 9.

Researchers suggest a minimum equilibrating period of one week (ASTM D 5298, Houston et al. 1994, Lee 1991). After the equilibration time, the procedure for the filter paper water content measurements can be as follows (Bulut et al., 2001):

1. Before removing the glass jar containers from the temperature room, all aluminum cans that are used for moisture content measurements are weighed to the nearest 0.0001 g. accuracy and recorded.
2. After that, all measurements are carried out by two persons. For example, while one person is opening the sealed glass jar, the other is putting the filter paper into the aluminum can very quickly (i.e., in a few seconds) using tweezers.
3. Then, the weights of each can with wet filter paper inside are taken very quickly.
4. Steps 2 and 3 are followed for every glass jar. Then, all cans are put into the oven with the lids half-open to allow evaporation. All filter papers are kept at 105 ±5^{o}C temperature inside the oven for at least 10 hours.
5. Before taking measurements on the dried filter papers, the cans are closed with their lids and allowed to equilibrate for about 5 minutes. Then, a can is removed from the oven and put on an aluminum block (i.e., heat sinker) for about 20 seconds to cool down; the aluminum block functions as a heat sink and expedites the cooling of the can. After that, the can with the dry filter paper inside is weighed very quickly. The dry filter paper is taken from the can and the cooled can is weighed again in a few seconds.
6. Step 5 is repeated for every can.

SOIL MATRIC SUCTION MEASUREMENTS

Soil matric suction measurements are similar to the total suction measurements except instead of inserting filter papers in a non-contact manner with the soil for total suction testing, a good intimate contact should be provided between the filter paper and the soil for matric suction measurements. Both matric and total suction measurements can be performed on the same soil sample in a glass jar as shown in **Fig. 2**. A testing procedure for matric suction measurements using filter papers can be outlined as follows:

1. A filter paper is sandwiched between two larger size protective filter papers. The filter papers used in suction measurements are 5.5 cm in diameter, so either a filter paper is cut to a smaller diameter and sandwiched between two 5.5 cm papers or bigger diameter (bigger than 5.5 cm) filter papers are used as protectives.
2. Then, these sandwiched filter papers are inserted into the soil sample in a very good contact manner (i.e., as in Figure 2). An intimate contact between the filter paper and the soil is very important.
3. After that, the soil sample with embedded filter papers is put into the glass jar container. The glass container is sealed up very tightly with plastic tape.
4. Steps 1, 2, and 3 are repeated for every soil sample.
5. The prepared containers are put into ice-chests in a controlled temperature room for equilibrium.

Researchers suggest an equilibration period of 3 to 5 days for matric suction testing (ASTM D 5298, Houston et al. 1994, Lee 1991). However, if both matric and total suction measurements are performed on the same sample in the glass jar, then the final equilibrating time will be at least 7 days of total suction equilibrating period. The procedure for the filter paper water content measurements at the end of the equilibration is exactly same as the one outlined for the total suction water content measurements. After obtaining all the filter paper water contents the appropriate calibration curve may be employed to get the matric suction values of the soil samples.

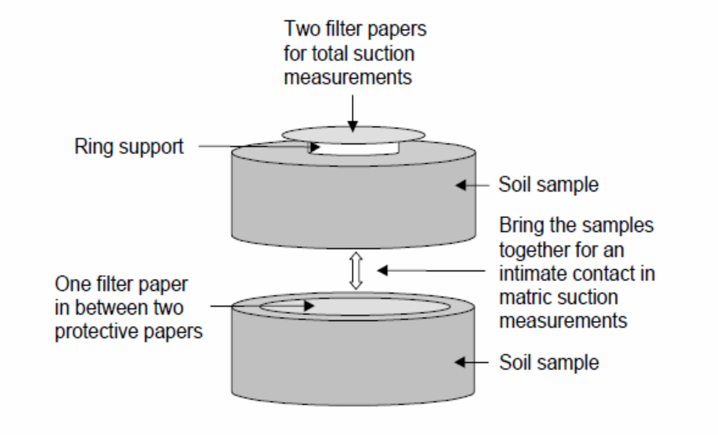
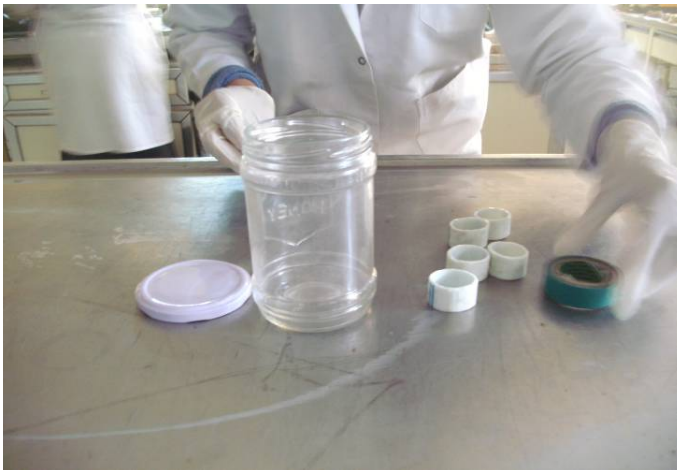


Fig. 2: Total and matric suction measurements (Bulut et al., 2001).



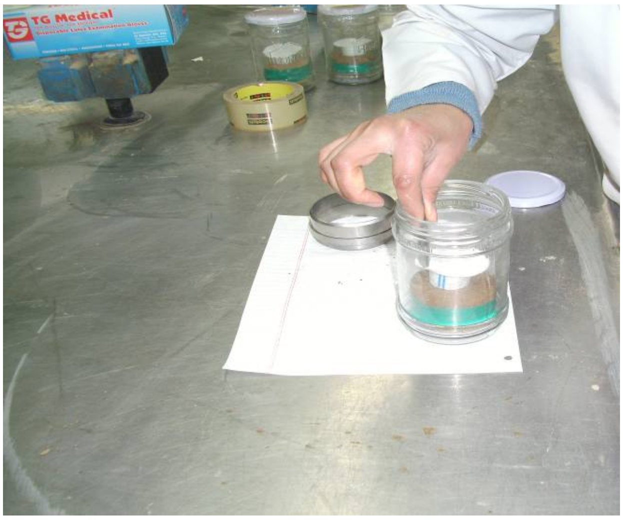
Photograph 1.

Photograph 2.

Photograph 3.

Photograph 4.

Photograph 5.



Photograph 6.

Photograph 7.

Photograph 8.

Photograph 9.

RESULTS AND DISCUSSION

The tests described in the previous section were carried out on five samples. A sample of the data measurement of soil suction by the filter paper method is shown in **Table 2**. The variation of the total and matric suction with the degree of saturation for the five soils is shown in **Figs. 3** and **4**, respectively. Both figures indicate that the suction increases with decrease of the degree of saturation.

Figs. 5 and **6** present the relationship between the total and matric suction and the filter paper water content. The relations are approximately linear and indicate decrease of suction with increase of the filter paper water content.

Figs. 7 and **8** show relationships between the soil consistency (liquid limit and plasticity index) and the total and matric suction, respectively at a degree of saturation equals to 70%. The figures indicate that the suction is measured for soils of low consistency (liquid limit < 40% or plasticity index < 20%). The measured suction becomes minimum at medium consistency (liquid limit ≈ 60% or plasticity index ≈ 40%).

Fig. 9 shows that the total and matric suction reveal decrease with the clay content and the suction decreases sharply when the clay content exceeds 80 %. The suction was measured for the soil having a clay content of about 70%.

The effect of the unconfined compressive strength on the suction is illustrated in **Fig. 10** which shows that the suction increases with the decrease of the soil shear strength. This may be attributed to the nature of flow through samples which becomes slower as the sample is stronger leading to generation of greater values of negative pore water pressure.

Table 2: Measurement of soil suction using filter paper – data sheet.

MEASUREMENT OF SOIL TOTAL SUCTION USING FILTER PAPER

SAMPLE NAME: RASAFA 1
DATE TESTED: 23-1-2011
DATE SAMPLE: 16-1-2011

Degree of Saturation %		70	80	90	100
Tin No.		1	2	3	4
Top Filter Paper (circle) (two filters)		Top	Top	Top	Top
Mass of Wet Filter Paper, g	M1	0.5482	0.5651	0.5651	0.5523
Mass of Dry Filter Paper, g	M2	0.4555	0.4607	0.4405	0.4193
Mass of Water in Filter Paper, g (M1-M2)	M_w	0.0927	0.1044	0.1596	0.1330
Water Content of Filter Paper % (M_w/M2)	Wf	20.3513	22.6612	28.2860	31.7195
Total Suction, (log kpa)	h_t	3.7416	3.5617	3.1258	2.8466

MEASUREMENT OF SOIL MATRIC SUCTION USING FILTER PAPER

SAMPLE NAME: RASAFA 1
DATE TESTED: 23-1-2011
DATE SAMPLE: 16-1-2011

Degree of Saturation %		70	80	90	100
Tin No.		5	6	7	8
Bottom Filter Paper (circle) (two filters)		Bottom	Bottom	Bottom	Bottom
Mass of Wet Filter Paper, g	M1	0.2929	0.3156	0.3303	0.3720
Mass of Dry Filter Paper, g	M2	0.2382	0.2371	0.2278	0.2294
Mass of Water in Filter Paper, g (M1-M2)	M_w	0.0547	0.0785	0.1025	0.1426
Water Content of Filter Paper % (M_w/M2)	Wf	22.9639	33.1084	44.9956	62.1622
Matric Suction, log kpa	h_m	3.5381	2.7478	1.8218	1.5728

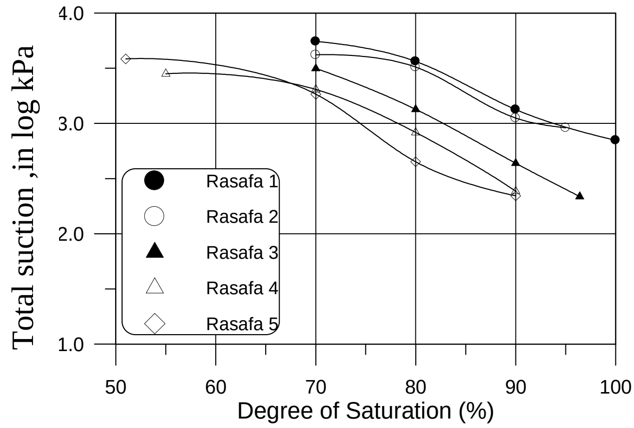


Fig. 3: Relationship between the total suction and degree of saturation.

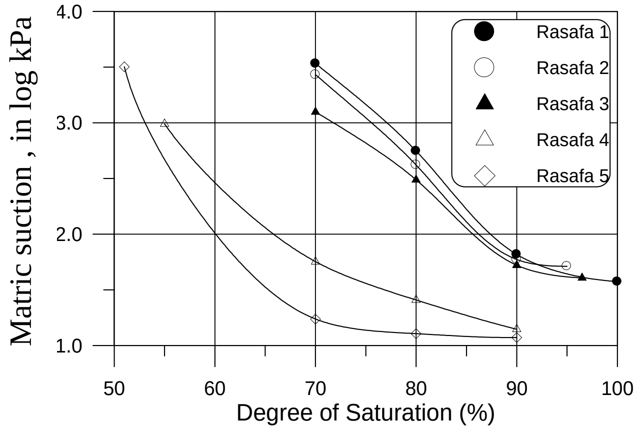


Fig. 4: Relationship between the matric suction and degree of saturation.

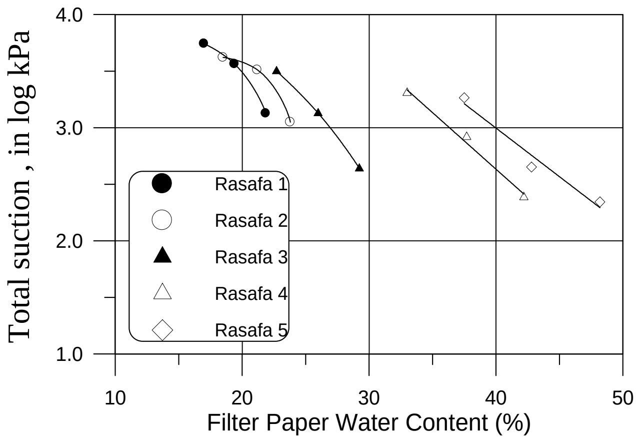


Fig. 5 Filter paper wetting curve (total suction).

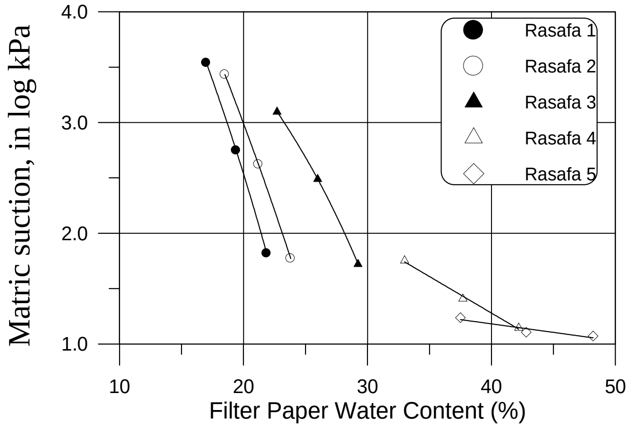


Fig. 6 Filter paper wetting curve (matric suction).

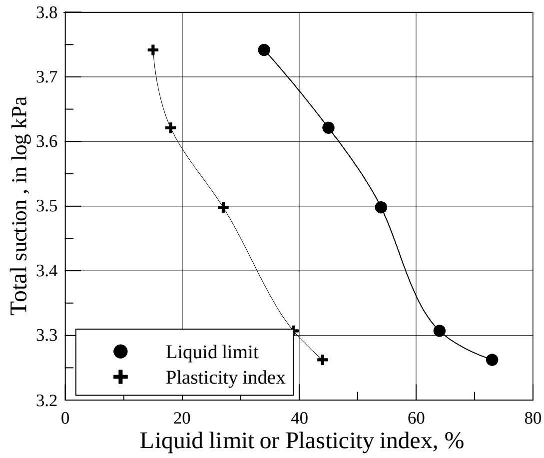


Fig. 7 Variation of the total suction with Atterberg limits at degree of saturation=70%.

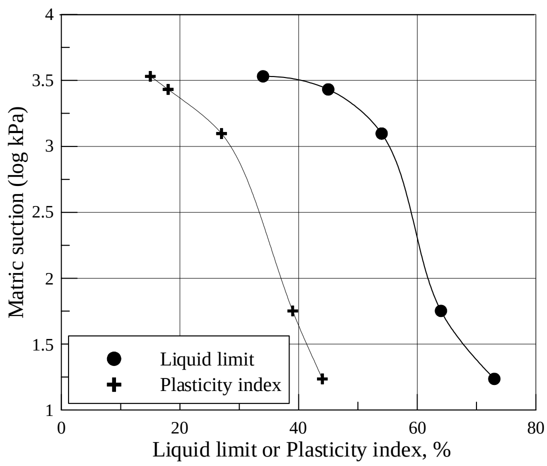


Fig. 8 Variation of the matric suction with Atterberg limits at degree of saturation=70%. .

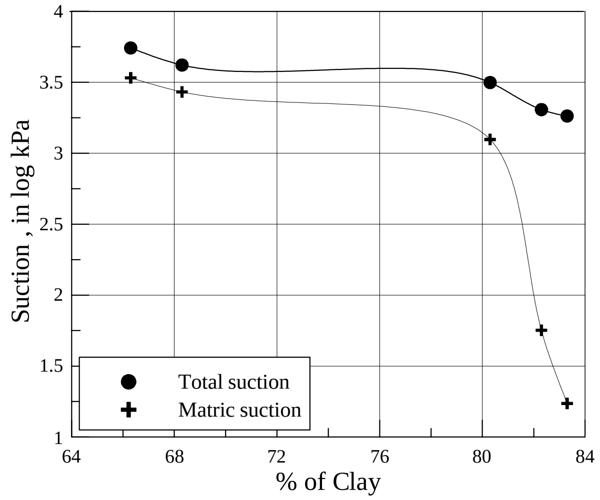


Fig. 9 Variation of the suction with the percentage of clay at degree of saturation=70%..

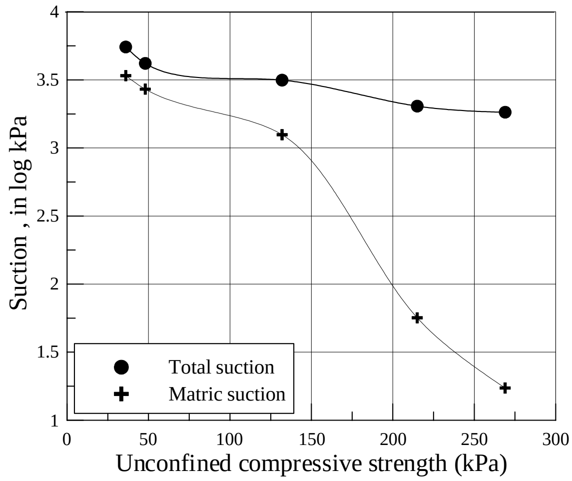


Fig. 10 Variation of the maximum suction with the unconfined compressive strength at degree of saturation=70%..

CONCLUSIONS

1. The suction increases with decrease of the degree of saturation. The relationships between the total and matric suction and the filter paper water content are approximately linear and indicate decrease of suction with increase of the filter paper water content.
2. The suction is measured for soils of low consistency (liquid limit < 40% or plasticity index < 20%). The suction was measured for the soil having a clay content of about 70%. The total and matric suction increase with the decrease of the Atterberg limit.

3. The total and matric suction increase with the decrease of the soil shear strength.

REFERENCES

- Al-Khafaf, S. and Hanks, R. J. (1974). “Evaluation of the Filter Paper Method for Estimating Soil Water Potential,” Soil Science, Vol. 117, No. 4, pp. 194-199.
- ASTM Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper (ASTM D 5298).
- Bulut, R., Lytton, R. L and Wray, W. K., (2001). “Soil Suction Measurements By Filter Paper**”,** Geotechnical Special Publication Number 115, Proceedings of Geo-Institute Shallow Foundation and Soil Properties Committee Sessions at the ASCE 2001 Civil Engineering Conference, pp. 243-261.
- Chandler, R. J. and Gutierrz, C. I. (1986). “The Filter Paper Method of Suction Measurements,” Geotechnique, Vol. 36, pp. 265-268.
- Fawcett, R. G. and Collis-George, N. (1967). “A Filter-Paper Method for Determining the Moisture Characteristics of Soil,” Australian Journal of Experimental Agriculture and Animal Husbandry, Vol. 7, pp. 162-167.
- Fredlund, D. G. and Rahardjo, H. (1993). Soil Mechanics for Unsaturated Soils, New York: John Wiley & Sons, Inc.
- Gardner, R. (1937). “A Method of Measuring the Capillary Tension of Soil Moisture Over a Wide Moisture Range,” Soil Science, Vol. 43, No. 4, pp. 277-283.
- Hamblin, A. P. (1981). “Filter Paper Method for Routine Measurement of Field Water Potential,” Journal of Hydrology, Vol. 53, No. 3/4, pp.355-360.
- Hamer, W. J. and Wu, Y.-C. (1972). “Osmotic Coefficients and Mean Activity Coefficients of Uni-Univalent Electrolytes in Water at 25oC,” Journal of Physics and Chemistry Reference Data, Vol. 1, No. 4, pp. 1047-1099.
- Houston, S. L., Houston, W. N., and Wagner, A. M. (1994). “Laboratory Filter Paper Measurements,” Geotechnical Testing Journal, GTJODJ, Vol. 17, No. 2, pp. 185-194.
- Lee, H. C. (1991). “An Evaluation of Instruments to Measure Soil Moisture Condition,” M.Sc. Thesis, Texas Tech University, Lubbock, Texas.
- McKeen, R. G. (1980). “Field Studies of Airport Pavement on Expansive Clay,” Proceedings 4th International Conference on Expansive Soils, Vol. 1, pp.242-261, ASCE, Denver, Colorado.
- McQueen, I. S. and Miller, R. F. (1968). “Calibration and Evaluation of a Wide-Range Gravimetric Method for Measuring Moisture Stress,” Soil Science, Vol. 106, No. 3, pp. 225-231.
- Murray, E. J., Sivakumar, V., (2010). “Unsaturated Soils A Fundamental Interpretation of Soil Behaviour”, John Wiley & Sons, Ltd., Publication.
- Schofield, R. K. (1935). “The pF of the Water in Soil,” Transactions, 3rd International Congress of Soil Science, Vol. 2, pp. 37-48.
- Swarbrick, G. E. (1995). “Measurement of Soil Suction Using the Filter Paper Method,” First International Conference on Unsaturated Soils, Eds.: E. E. Alonso and P. Delage, Vol. 2, Paris, 6-8 September, ENDPC, pp. 701-708.