European Scientific Journal March 2013 edition vol.9, No.9 ISSN: 1857 – 7881 (Print) e - ISSN 1857- 7431

EFFECT OF SALT CONTENT ON TOTAL AND MATRIC SUCTION OF UNSATURATED SOILS

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Abstract

Soils located above the groundwater table are generally unsaturated and possess negative pore-water pressures. A soil-water characteristic curve (SWCC) that relates the water content of a soil to matric suction is an important relationship for the unsaturated soil mechanics. The SWCC essentially shows the ability of an unsaturated soil to retain water under various matric suctions. The filter paper method is a soil suction measurement technique. 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.

In this paper, three soil samples were collected from three sites within Baghdad city in Iraq. 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. The soil samples were mixed with different percentages of Nacl salt.

It was concluded that the suction increases with the 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 the increase of the filter paper water content. All soil samples exhibit unique linear relationship between the total suction and filter paper water content and matric suction. When salt exists in the soil, there is a noticeable increase in both matric and total suction.

Keywords: Total suction, matric suction, salt content, filter paper, unsaturated soil

Introduction

The knowledge of unsaturated soil is indispensable for several hydrological and Geoenvironmental problems such as permeation of water through vadoze zone, ground water recharge, and deciding irrigation requirements for crops. The accuracy of these studies depends on the precise characterization of unsaturated soil, which includes the development of the soil suction–water content relationship (SWR) or soil–water characteristic curve (SWCC). It is believed that each soil has a unique SWCC. However, past studies clearly indicate that there are different parameters that would influence the uniqueness of the SWCC.

The effects of irrigating fresh water onto sodic soils, or saline irrigation water onto soils, is well documented in the literature (Shainberg et al., 1981; Sumner, 1993). Most studies appear to have been conducted on soils from arid or semi-arid regions that have 2:1 clay minerals as an important component of the clay mineral fraction, low organic matter contents, and often poor natural structure. Many studies have shown that the soil exchangeable sodium percentage generally increases linearly with SAR of irrigation water (Sumner, 1993).

There is increasing anecdotal evidence from some land treatment sites that irrigating sodium-contaminated wastewaters onto soils may be causing soil structural problems and reduced permeability. The effect of irrigating such waste (derived from agricultural industries) on soil physical and chemical properties was investigated by Menneer et al. (2001) in an Allophanic soil (Te Puninga silt loam) and a Gley soil (Waitoa silt loam). Wastewater irrigation at the sites investigated had taken place, with sodium adsorption ratios (SAR) of the wastewater varying between 17 and 51 [(mmol/L).sub.0.5]. Increases in exchangeable sodium percentage (ESP) were recorded to 300 mm depth in both soils. At the soil surface (0-20 mm), ESP had increased to 31%, compared with 0.4% at control sites.

Saturated and unsaturated hydraulic conductivity measurements carried out at irrigated sites in the field showed no evidence of reduced conductivity in the surface soil until a pressure head of -120 mm was applied, the decrease being greater for the Te Puninga soil than the Waitoa. These results, along with the laboratory studies, suggest that whereas there may have been some structural deterioration in the soil matrix as a result of irrigation with the waste water, macropore flow at higher moisture contents in the field was sufficient to overcome any adverse effects. It is suggested that laboratory studies using repacked soil may have limited use in predicting effects of Na-contaminated wastewater on soil hydraulic properties in structured soils. The results also further support suggestions that organic matter dissolution in Na-affected soils may affect soil physical properties.

Rao and Shivananda (2005) examined the influence of extraneous salt addition on pore-fluid osmotic suction of a clay soil. The dependence of swell potentials of the salt-amended clay specimens on initial pore-fluid osmotic suction is also examined. The osmotic suctions predicted by Van't Hoff's equation are in excess or smaller than the values calculated from the pore water electrical conductivity, depending on whether the Van't Hoff factor in the Van't Hoff equation is included or not. Experimental results suggest that the salt-amended specimens absorbed water and swelled in response to matric suction and chemical concentration gradients on inundation with water in oedometer cells. Salt also diffused from the soil pores of salt-amended specimens to the reservoir water in oedometer cells in response to chemical concentration gradients. Reduction in effective stress from the osmotic flow into the soil specimen and increase in interparticle repulsion from a reduction in pore-water salt concentration rendered the total swell potentials of salt-amended specimens independent of initial pore-fluid osmotic suction. The initial pre-fluid osmotic suction does, however, significantly affect the rate of swelling.

Extensive research works were conducted in the past utilizing plant roots and stems as slope stabilization elements by means of mechanical reinforcement. However, hydrological benefits provided by plant-induced suction through transpiration are often overlooked. Woon et al. (2011) tried to measure and identify any suction influence zone induced by bermudagrass (*Cynodon dactylon*) in completely decomposed granite (CDG; silty sand) in laboratory. The CDG was compacted in a rectangular test box at a degree of compaction of 80% and the grass was allowed to germinate on the soil surface. The test box was instrumented with heat dissipation matric water potential sensors, which allow matric suction up to 350 kPa to be measured indirectly. The setup was placed in a plant room, where atmospheric conditions such as temperature, solar energy and relative humidity were controlled and measured. For comparison purposes, a control experiment (without vegetation), which has an identical experimental setup, was performed. Variations of matric suction between the vegetated and bare specimens were measured and compared. Any grass-induced suction influence zone was identified, in terms of magnitude and distribution.

The study of Malaya and Sreedeep (2012) purports to critically review the findings reported in the literature to reveal the influence of different parameters on the SWCC. The review was divided into two sections. The first section deals with those parameters that need a critical assessment, and the second section deals with apparent factors that influence the

SWCC. The critical evaluation brings out the anomalies associated with the influence of some of the parameters, such as compaction state, measurement procedures, stress history, and range of suction measurement on the SWCC. Compaction water content has a more significant influence on the SWCC than density. The SWCC was found to be unique at a high range of soil suction for which adsorptive forces are predominant. It was found that the extent of influence of parameters on the SWCC is soil specific. However, further experimental investigations are required to quantify soil-specific parametric influence on the SWCC.

This paper evaluates both the total and matric suctions for samples taken from three sites in Baghdad city. These soils have different properties and they were prepared at different degrees of saturation. The aim of this paper is to investigate the effect of salt content of the total and matric suctions and soil properties.

Main Text

A Brief Historical Background

There are many soil suction measurement techniques and instruments in the fields of soil science and engineering. Most of these instruments have limitations with regard to range of measurement, equilibration times, and cost. Therefore, there is a need for a method which can cover the practical suction range, 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 soils in an unsaturated state 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 behavior 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 or 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:

$$ht = hm + h\pi \qquad (1)$$

where ht = total suction (kPa),

hm = matric suction (kPa), and

hπ = osmotic suction (kPa).

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

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

where R = universal gas constant,

T = absolute temperature,

V = molecular volume of water,

P / Po = relative humidity,

P = partial pressure of pore water vapor, and

Po = saturation pressure of water vapor over a flat surface of pure water at the same temperature.

It should be noted that these two forms of soil suction are completely independent and have no effect on each other. If the soil is granular and free of salt, there is no osmotic suction and matric and total suction are equal. However clays contain salts and these salts cause a reduction in the vapor pressure. This results in an increase in the total suction, and this increase is the energy needed to transfer water into the vapor phase (i.e. the osmotic suction) (Simth and Smith, 1998).

Matric suction is known to vary with time due to environmental changes. Any change in suction affects the overall equilibrium of the soil mass. Changes in suction may be caused by a change in either one or both components of soil suction. The role of osmotic suction has commonly been associated more with unsaturated soils than with saturated soils.

However, osmotic suction is related to the salt content in the pore-water which is present in both saturated and unsaturated soils. The role of osmotic suction is therefore equally applicable to both unsaturated and saturated soils. Osmotic suction changes have an effect on the mechanical behavior of a soil. If the salt content in a soil changes, there will be a change in the overall volume and shear strength of the soil (Fredlund and Rahardjo, 1993).

In the case where the salt content of the soil is altered by chemical contamination, the effect of the osmotic suction change in the soil behavior may be significant. In this case, it is necessary to consider osmotic suction as part of the stress state. This applies equally for saturated and unsaturated soils. The role played by osmotic suction in influencing the mechanical behavior of a soil may or may not be of the same quantitative value as the role played by matric suction. The osmotic suction is more closely related to the diffise double layer around the clay particles, whereas the matric suction is mainly associated with the air-water interface (i.e., contractile skin) (Fredlund and Rahardjo, 1993).

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 a 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 inches (8.89 to 10.16 cm) diameter can contain the 3 inch (7.62 cm) diameter Shelby tube samples very nicely. 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, three soil samples were collected from three sites within Baghdad city. 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. Compaction 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
Soil 1	50	25	25	2.79	72
Soil 2	41	22	19	2.77	60
Soil 3	30	20	10	2.75	52

The grain size distribution of the three samples is shown in Figure 1. The figure shows that all these soils are classified as silty clay.

The soil samples were mixed with different percentages of Nacl salt. Standard compaction test was carried out on these samples following ASTM D-1196-93 specification. The results of compaction test are summarized in Table 2 which indicates that for the three soils, the optimum water content decreases with increase of salt content while the maximum dry unit weight increases. This can be attributed to the electrical charges provided by salts which increase the double layer repulsions of clay particles.

Because the quantity h_s. $\square_w$(h$_s$. is the osmotic saturation head and $\square_w$ is the unit weight of water) is an osmotic pressure and the salt concentration between particles will invariably be greater than at points away from the soil (such as in a piezometer), h_s. $\square_w$ will be negative. This pressure reflects double-layer repulsions.

Some saline soils with high contents of salts can undergo changes in volume associated with hydration– dehydration phenomena. One example is the swelling of some soils containing large amounts of sodium sulfate (Na_2SO4).

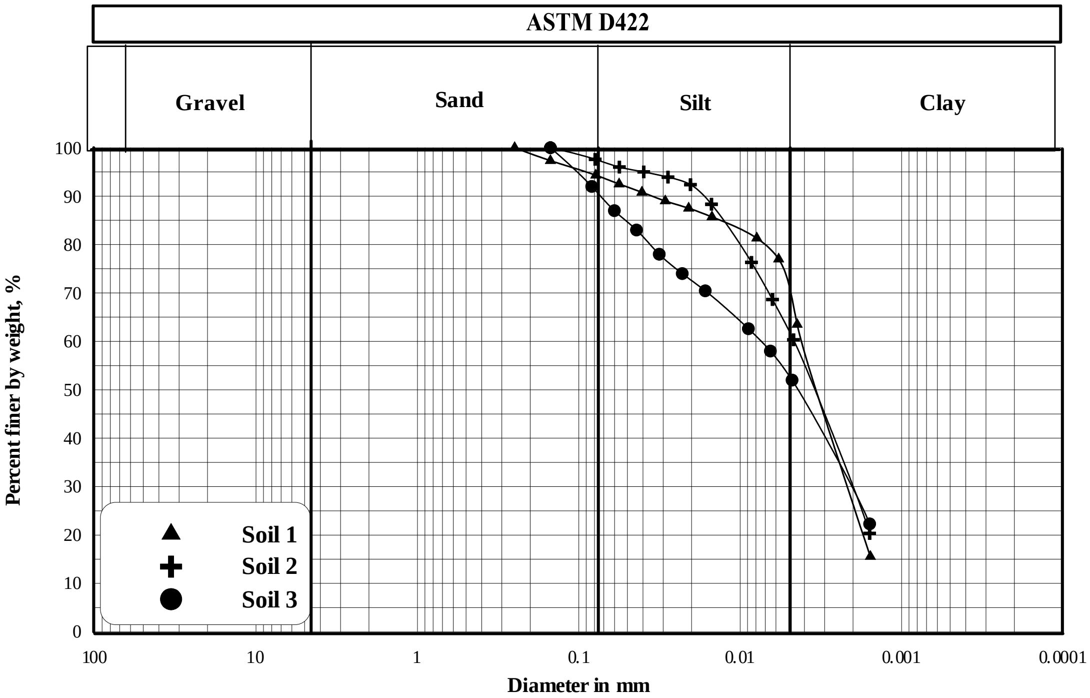


Fig. 1: Grain size distribution.

Table 2: Results of compaction tests.

Sample	% Salts	Optimum moisture content (%)	Maximum dry unit weight (kN/m^3)
Soil 1	0%	13.75	17.13
	7%	13.5	18.3
	10%	12.6	18.57
	13%	12.1	18.84
Soil 2	0%	13.51	17.57
	7%	12.01	18.42
	10%	11.80	18.59
	13%	11.48	18.68
Soil 3	0%	12.83	17.73
	7%	11.63	18.89
	10%	11.40	19.00
	13%	11.00	19.14

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 metric and total suction measurements can be performed on the same soil sample in a glass jar as shown in Figure 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 protection.

2. Then, these sandwiched filter papers are inserted into the soil sample in a very good contact manner (i.e., as in Figures 2 and 3). 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.

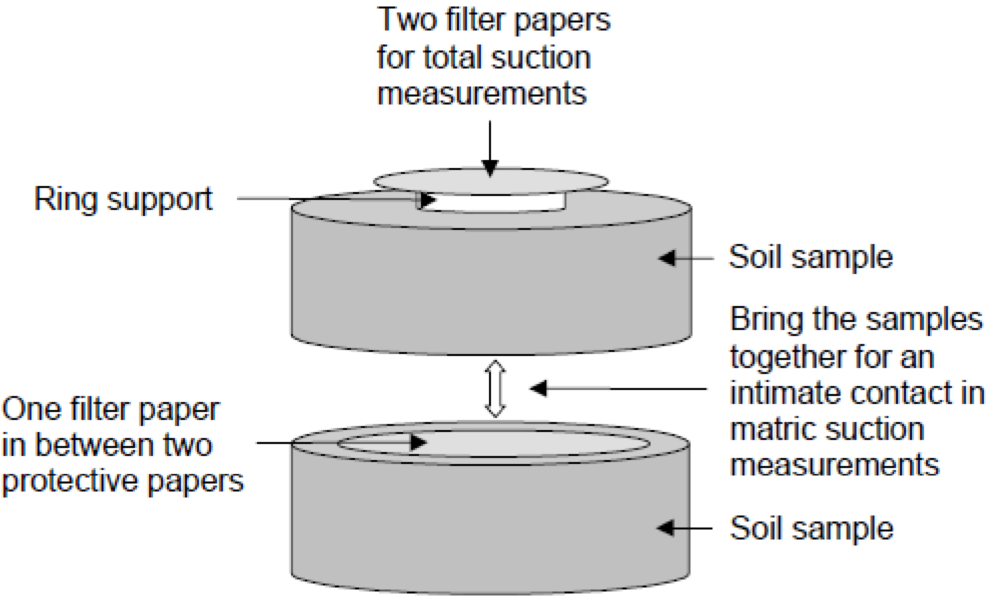
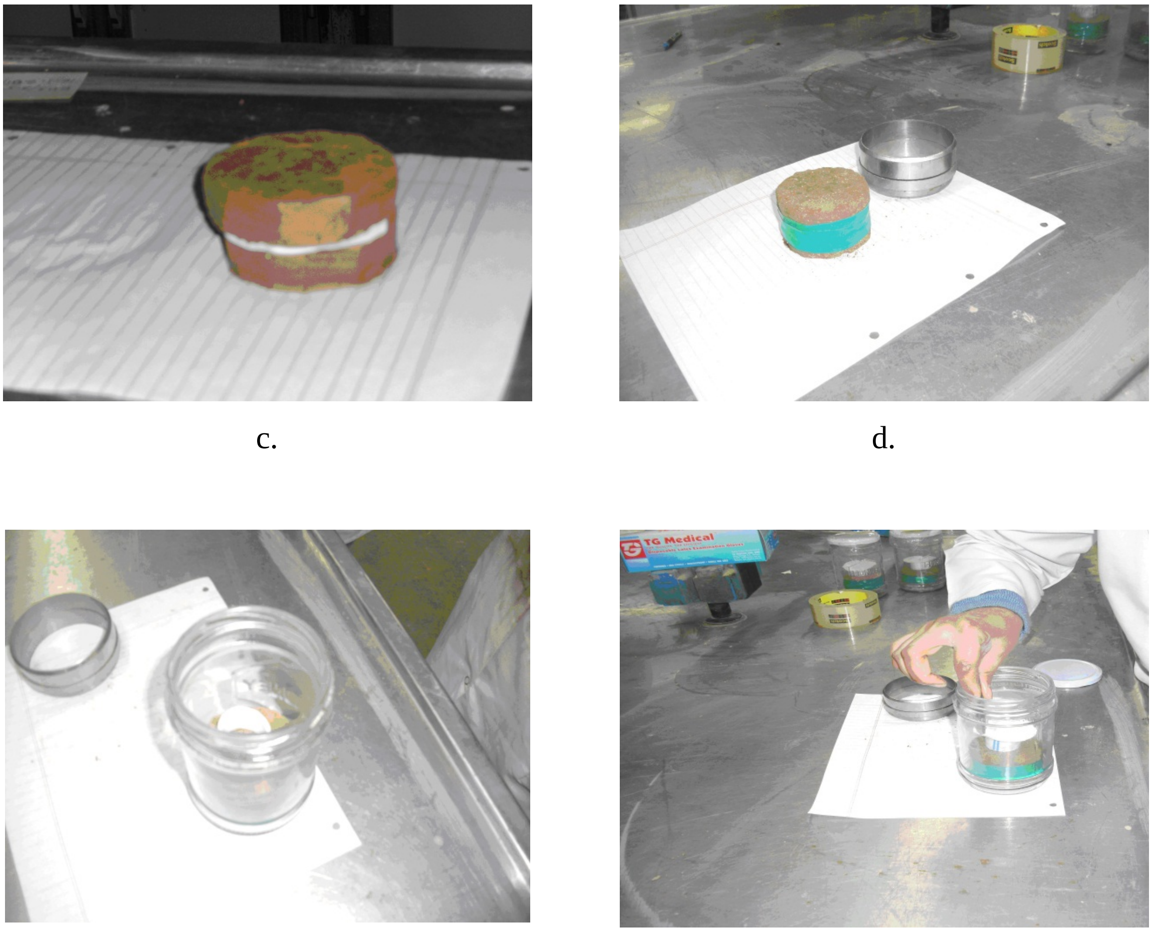


Fig. 2: Total and matric suction measurements (Bulut et al., 2001).


a.

b.



c.

d.

e.

f.

Fig. 3: Steps of filter paper test.

Results and Discussion

The tests described in the previous section were carried out on the three samples. The variation of the total suction with the degree of saturation for the three soils is shown in Figure 4. The figure indicates that the suction increases with the decrease of the degree of saturation.

Figures 5, 6 and 7 present the relationship between the matric suction and the degree of saturation for soils 1, 2 and 3, respectively mixed with different percentages of Nacl salt. The relations indicate decrease of matric suction with increase of degree of saturation and decrease of soil salt content.

The same trend is observed in Figures 8 to 10 for the relationship between the total suction and degree of saturation. One considerable point is noticed in these relations that when salt exists in the soil, there is a noticeable increase in both matric and total suction.

Figures 11 to 13 present the relationship between the total suction and the filter paper water content while Figures 14 to 16 present the relationship between the 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.

It can be noticed that all soil samples exhibit unique linear relationship between the total suction and filter paper water content and matric suction. This means that all the soils show linear increase in both matric and total suction with increase of salt content.

The total and matric suction curves are almost congruent one to another, particularly in the higher water content range. In other words, a change in total suction is essentially equivalent **to** a change in the matric suction**.** For most geotechnical problems involving unsaturated soils, matric suction changes can be substituted for total suction changes, and vice versa (Fredlund and Rahardjo, 1993).

Considering a simple analogy between soil pore water and a salt solution, equilibrium requires that the chemical potential of the water vapor in the gas phase be the same as the chemical potential of the solution in the liquid phase. Because the addition of dissolved solutes has reduced the chemical potential of the solution relative to the condition for pure water, a smaller amount of water tends to evaporate to the vapor phase. In other words, the reduced energy of the liquid phase inhibits the transfer of mass and energy to the vapor phase (Lu and Likos, 2004).

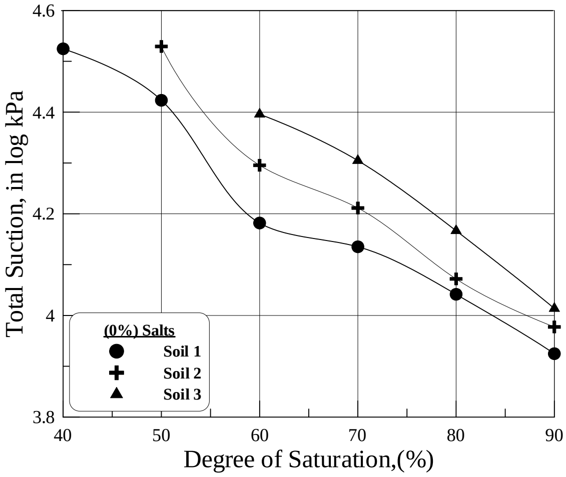


Fig. 4: Relationship between the total suction and degree of saturation for the three soils.

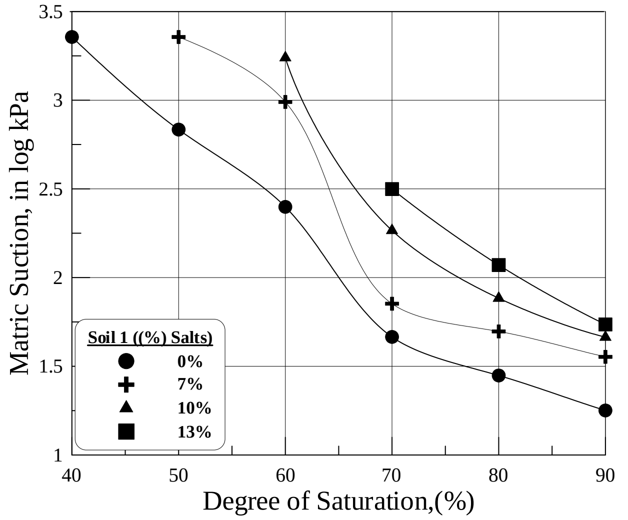


Fig. 5: Relationship between the matric suction and degree of saturation for soil 1 mixed with different percentages of salt.

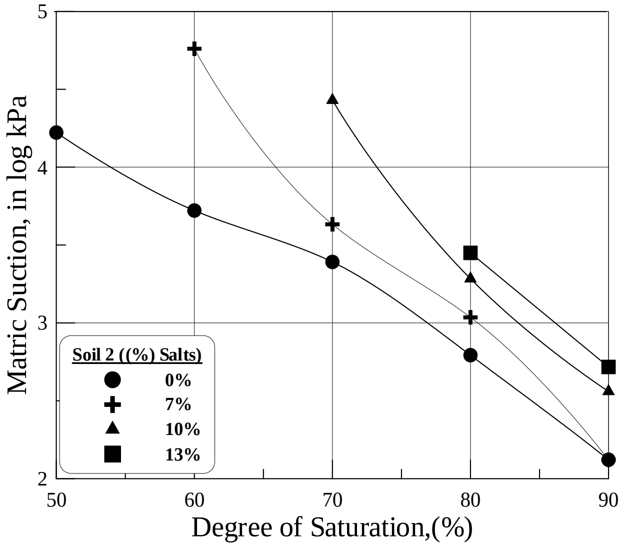


Fig. 6: Relationship between the matric suction and degree of saturation for soil 2 mixed with different percentages of salt.

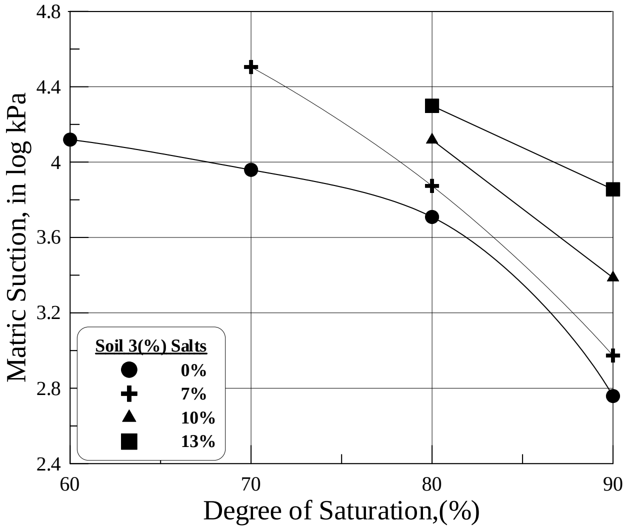


Fig. 7: Relationship between the matric suction and degree of saturation for soil 3 mixed with different percentages of salt.

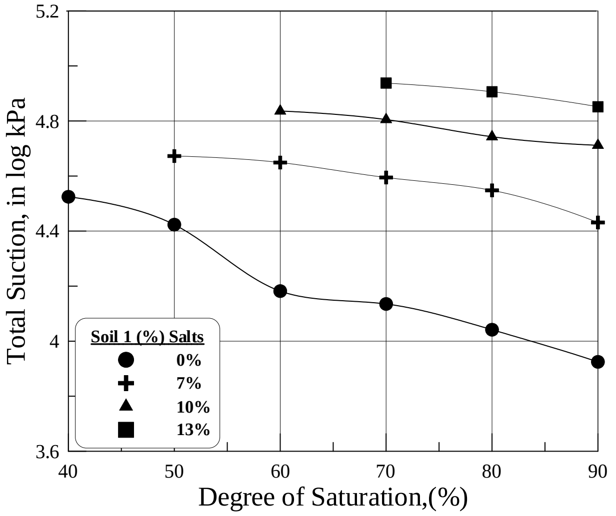


Fig. 8: Relationship between the total suction and degree of saturation for soil 1 mixed with different percentages of salt.

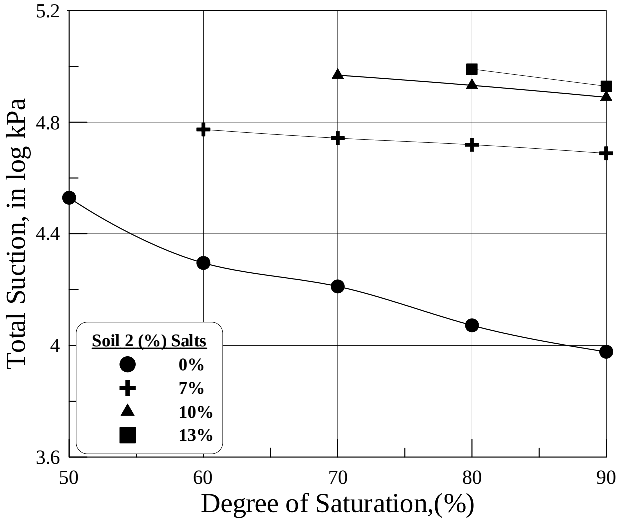


Fig. 9: Relationship between the total suction and degree of saturation for soil 2 mixed with different percentages of salt.

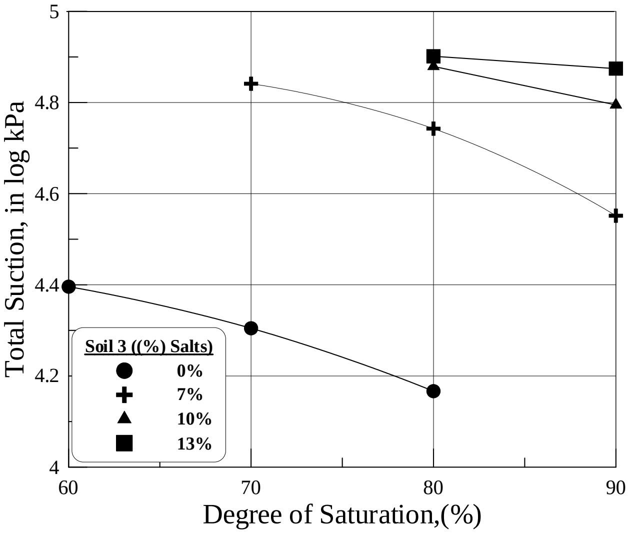


Fig. 10: Relationship between the total suction and degree of saturation for soil 3 mixed with different percentages of salt.

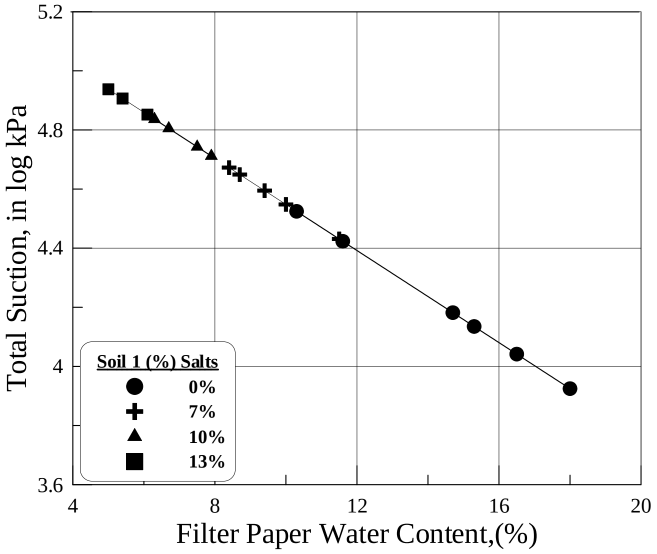


Fig. 11: Relationship between the total suction and filter paper water content for soil 1 mixed with different percentages of salt.

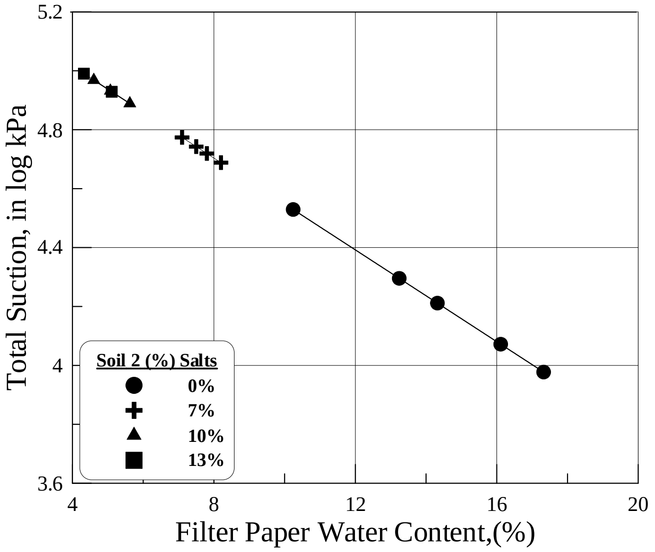


Fig. 12: Relationship between the total suction and filter paper water content for soil 2 mixed with different percentages of salt.

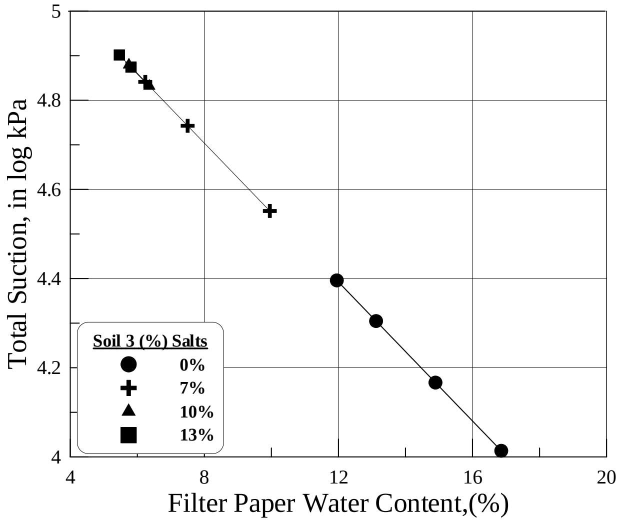


Fig. 13: Relationship between the total suction and filter paper water content for soil 3 mixed with different percentages of salt.

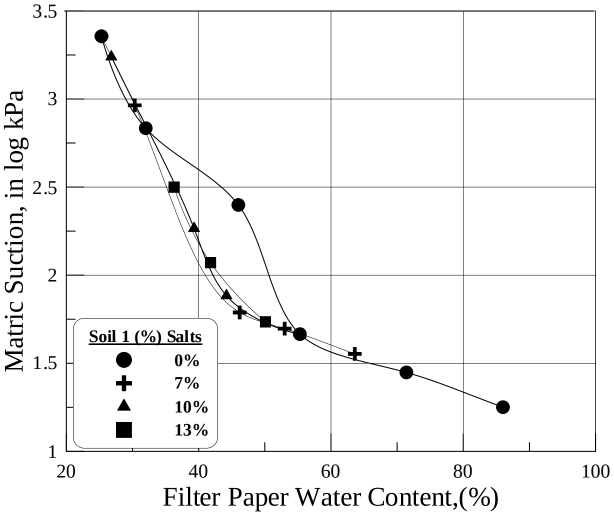


Fig. 14: Relationship between the matric suction and filter paper water content for soil 1 mixed with different percentages of salt.

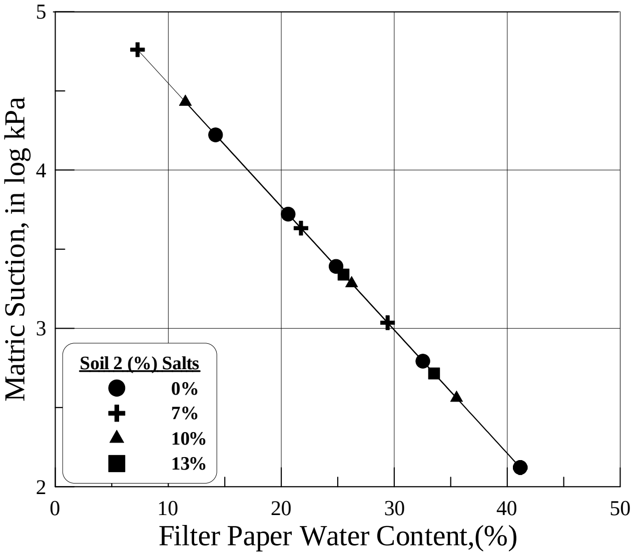


Fig. 15: Relationship between the matric suction and filter paper water content for soil 2 mixed with different percentages of salt.

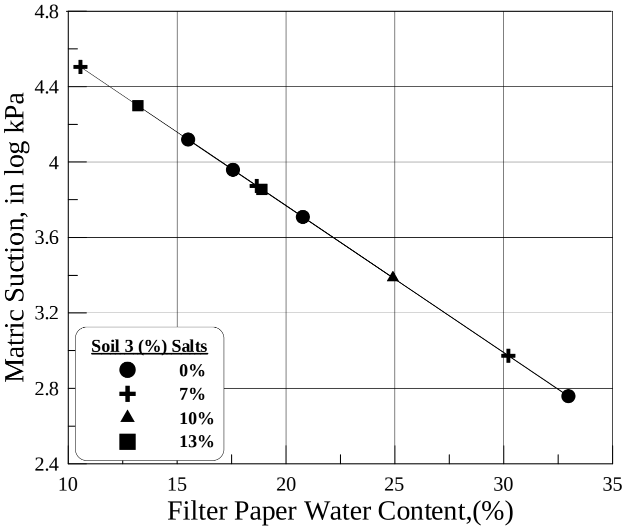


Fig. 16: Relationship between the matric suction and filter paper water content for soil 3 mixed with different percentages of salt.

Conclusion

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. All soil samples exhibit unique linear relationship between the total suction and filter paper water content and matric suction.
2. The maximum suction is measured for soils of low consistency (liquid limit < 40%). The maximum suction was measured for the soil having a clay content of about 70%.
3. When salt exists in the soil, there is a noticeable increase in both matric and total suction.

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 D 5298 - Standard Test Method for Measurement of Soil Potential (Suction) Using Filter Paper, American Society for Testing and Materials 1999. ASTM Standards, Vol. 0408, West Conshohocken, Pa.

ASTM D1196-93 (Reapproved 2004):" Standard Test Method for Non repetitive Static Plate Load Tests of Soils and Flexible Pavement Components, for Use in Evaluation and Design of Airport and Highway Pavements1", Annual book of ASTM Standards: Volume 04.08, 2004, Soil and Rock.

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.

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.

Lu, N., Likos, W. J., (2004), “Unsaturated Soil Mechanics”, John Wiley & Sons.

Malaya, C., Sreedeep, S., (2012). ”Critical Review on the Parameters Influencing Soil-Water Characteristic Curve.” Journal of Irrigation and Drainage Engineering, ASCE, 138(1), pp. 55–62.

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.

Menneer, J. C., McLay, C. D. A., Lee, R., (2001). “Effects of Sodium-contaminated Wastewater on Soil Permeability of Two New Zealand Soils”, Australian Journal of Soil Research, Publisher: CSIRO Publishing Audience, 39 (4).

Murray, E. J., Sivakumar, V., (2010). “Unsaturated Soils A Fundamental Interpretation of Soil Behaviour”, John Wiley & Sons, Ltd., Publication.

Rao, S. M., Shivananda, P., (2005). “Role of Osmotic Suction in Swelling of Salt-Amended Clays”, Canadian Geotechnical Journal, 44(5), pp. 520-532.

Shainberg, I., Rhoades, J. D., Prather, R. J., (1981). “Effect of Low Electrolyte Concentration on Clay Dispersion and Hydraulic Conductivity of a Sodic Soil”, Soil Science Society of America Journal, 45, pp. 273-277.

Smith, G.N., and Smith, Ian, G.N., (1998), "Elements of Soil Mechanics", Seventh edition, published by Blackwell Seience.

Sumner, M. E., (1993). “Sodic Soils: New Perspectives”, Australian Journal of Soil Research 31, pp. 683-750.

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.

Woon, K. X., Leung, A. K., Ng, C. W. W., (2011). "An Experimental Investigation on Suction Influence Zone Induced by Plant Transpiration”, Proceedings of the Conference on “Unsaturated Soils: Theory and Practice”, 2011, Jotisankasa, Sawangsuriya, Soralump and Mairaing (Editors), Kasetsart University, Thailand, pp. 861-866.