MOISTURE MOVEMENT THROUGH SWELLING SOIL IN RELATION TO ITS PHYSICAL PROPERTIES CHANGE

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ABSTRACT

Th prediction of the water amount and its movement through natural expensive soils due to the water of irrigation or ground water is very important in many Engineering problems. This movement affects the drainage efficiency, pollutant movement, design of public and water structures and safety of the lining of irrigation canals...etc. The present study is carried out to investigate the effect of physical properties change of natural expansive soil from many different geographic locations in Egypt on its hydraulic characteristics and its water holding capacity. Using the finite element technique and minimizing the square error between the experimentally measured water content and that calculated from the theoretical model, the water characteristics of all different soils could be predicted. The results showed that the physical properties change of these soils due to swelling has a major effect on the water movement through these soils and on the water holding capacities of the studied soils. The swelling of these soils improves their cultivation characteristics.

1- INTRODUCTION:

Expansive soils are found in arid and semi-arid regions. Where as the development of land reclamation project are increased due to the increase of the economical growth, the irrigation projects and new cities should be constructed on these soils. The damage of canal linings, retaining walls and piers of bridges, pavements and other constructions due to the swelling pressure of expansive soils leads to a big economical loss. The expansive capacity of a soil depends upon the type and amount of clay minerals and the exchangeable bases [1]. Out of the three major clay mineral groups montmorillonite, illite and kaolinite, the montmorillonite clay minerals swell when coming in contact with water, while the clay mineral of the other two groups swell considerably less. Many studies have been carried out on determining the excess of pressure on the footings of the structures due to the expansion of these soils and the percent of this expansion [2, 3, 4]. Katti et al. [5] studied the depth effect on swelling in expansive clay. They concluded that no vertical swell occurred below around 760 mm depth. Wet-dry cycle effect on the design of piers was studied by Gromki [6].

Prediction of water characteristics of natural expansive soils can be helpful in finding the moisture content and the polutent movement due to irrigation or ground water movement, the seepage and the drainage capacity of these soils. The movement of ground water table in these soils has a major water characteristics of natural expensive soils from different geographic locations in Egypt. The effect of physical properties change on the water holding capacity of these soils is studied.

2-THEORETICAL BACKGROUND:

In this study, the used technique for estimating the soil-water characteristics is composed of two parts. The first part is a laboratory test for making the unsaturated flow in a specimen. The side wall of a soil specimen was completely prevented to evaporate water. A constant zero-pressure was given at the bottom of the soil specimen (see Fig. 1). When the air humidity above the top surface of this speismen is low, water is evaporated from this surface and water contained in this specimen is upwardly flowing. Then one dimensional unsaturated flow was created in the soil specimen. The average evaporation rate from the top surface of the specimen can be measured by weight. This evaporation rate is the boundary flux condition on the top surface. The saturation distribution in the specimen is measured after the test. Because the boundary conditions are well described and the flow is simple, and when the hydraulic parameters defining the water characteristics of the soil specimen are known, the vertical saturation distribution can be calculated by solving the following Rechard's equations;

$$C(\theta)\frac{\partial h}{\partial t} = k_s . r(\theta)\frac{\partial^2 h}{\partial z^2} + E \qquad (1)$$

$$h = z + \psi \qquad (2)$$

where, θ is the saturation, C is the specific moisture capacity, k_s is the saturated hydraulic conductivity, r is the relative hydraulic conductivity, E is the sink or source term, z is the height from a reference level and ψ is the capillary pressure head.

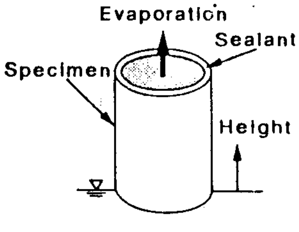


Fig. 1 Soil specimen and boundary conditions

The second part of the used technique for estimating the soil-water characteristics is the back analysis of the flow in the specimen which was the reverse procedure for estimating the water characteristics from the measured saturation distribution [7]. The saturation distribution were calculated under the boundary conditions that are identical to the laboratory test and the assumption of the soil-water characteristics. Every calculated distribution is compared with the measured one and the best water characteristics by which the measured distributions was well reconstructed was looked for. The procedure was mathematically performed. The van-Genuchten [2]model (1980) was adopted for presenting the water characteristics of soils (see appendix 1).

3- EXPERIMENTAL SET UP:

3-1-Introduction: After the study of Katti et al. [5] on the depth effect on the swelling of

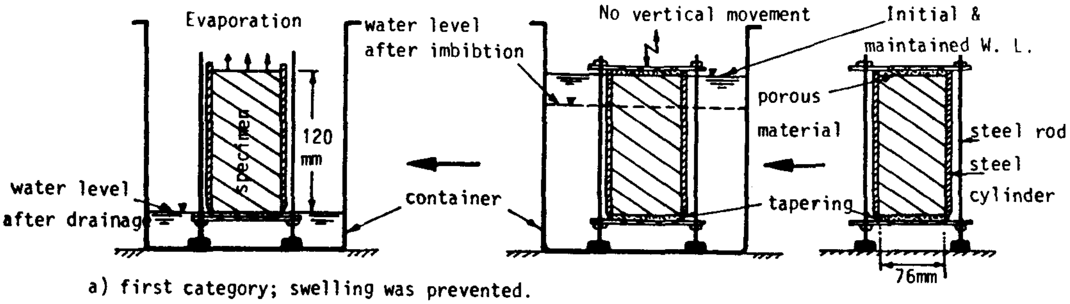
on its water characteristics, the expansive clay soils from different locations in Egypt under two different conditions are studied in two categories:
i) First, soils were prevented to swell; the aim of this test is to determine the hydraulic characteristics of expansive soil as it was at a deep depth.
ii) Second, soils were allowed to swell; in this test the relations between soil water-content and dry density were predicted and the soil-water characteristics at the final stage of swelling process were predicted as well.

3-2- Soil water Characteristics Determination:

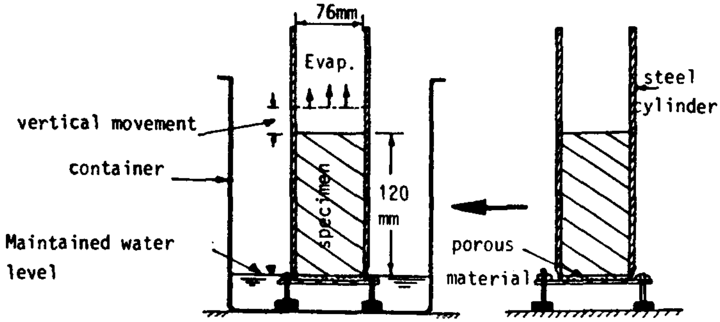
As mentioned before, the measured evaporation from the top of a soil specimen and zero pressure at the bottom were used as boundary conditions in the back analysis technique. So, in the first category, where soils were prevented to swell, these two parameters could be determined as follows: steel tubes have one edge tapered to go through the soil for extracting undisturbed soil specimens were used for sampling soils from the different locations. Every tube has 76mm internal diameter and 140 mm long. A porous stones have 13 mm thickness were placed at the top and at the bottom of the specimens to prevent the fine particles of soil from escaping out under swelling pressure. To allow water to reach the specimen at its bottom edge and air to escape from the upper one and to make the specimen under control, two steel discs having 125mm diameter, 5 mm thickness and a number of holes (3 mm diam.) were placed at the top and the bottom of the specimen and fitted with 3 steel rods of 6 mm diameter as shown in Fig.(2a). The soil specimen was submerged in container filled with water till its top edge. A known water volume was imbibed by the specimen. This water volume was measure as the decrease in water surface from the original out-side the specimen. Water was added to maintain the original till no more imbibtion of water by the specimen. At this moment the specimen was fully saturated.

To measure the evaporation during drying process, the water level in the container was lowered to the bottom of the specimen. Then water was allowed to drain at this bottom and the drained water was removed till the drainage process was vanished, so the evaporation from the top of the soil specimen was allowed after removing the upper steel disc and the porous cap. The evaporation rate was measured by weighting intervally the container with the soil specimen. The rate of evaporation was used in the back analysis. Finally the specimen was subdivided into several samples and the water content distribution was gravitationally measured and the saturation distribution was calculated and used in the back analysis.

In the second category, where soils were allowed to swell. To predict the relation between soil water content and the change of its dry density and to predict the soil-water characteristics at the stable stage of its swelling, the test procedures were as follow. As mentioned in the first category, steel tubes were used for extracting the soil specimens, but in this test the tubes have 250 mm long instead of 140 mm (Fig. 2 b) to allow for the vertical movement at the top of the specimen due to swelling and no porous stone and steel disc at the top. The soil specimen was placed in a container partially filled with water. The water level was maintained at the bottom of the specimen. The imbibed water by the specimen was replaced by adding a known volume of water to the container with time. As a result of imbibtion water by the specimen the soil was swelled and the vertical movement with the time was recorded and the water content was calculated from the known imbibed water volume. Whereas the dry weight of soil not change, the dry density of soil is changed by the change of the volume, then a relation between dry density with the water content could be predicted for each soil. At the stage of no more vertical movement of soil in the tube (stable stage), the evaporation rate was recorded with the time as described in the first category and finally the saturation distribution was measured and the both were used in the back analysis



a) first category; swelling was prevented.



b) second category ; swelling was allowed

Fig. 2 Experimental set-up

4- OBSERVATIONS:

During the course of the experimental tests it is noticed that, the rate of the evaporation for the period from the first of February to the end of July 2001 from the tested soils was almost about 3 or 5mm/day under the weather conditions in the gallery of the hydraulic laboratory of Civil Engineering Department, Assiut University. The lower rate was from the specimens of the second category. This low rate may be attributed to the observed low water content at the top of these specimens and the capacity of undisturbed soil specimens of the first category to supply water was still higher than that of the disturbed soil specimens due to swelling. Also, it was observed that the rate of vertical movement due to swelling was high at the beginning of the test where the water content was small. This rate was decreased with the time. Also, it was observed that for the soil had low in-situ water content, the total vertical swelling of this soil was higher than that of high insitu water content even it was extracted from the some location. From the observations also, the rate of upwardly movement of water in the soil which was allowed to swell (second category) was slower than that in the soils of first category.

5- DISSCUTION OF THE RESULTS:

saturation. From the experimentally measured saturation distribution and minimizing the square error between the calculated saturation distribution and the measured one for each soil type the unknown parameters in the model of the unsaturated flow are inversely estimated (see appendix 2). consequently the relations between the saturation and capillary pressure head, hydraulic conductivity and diffusivity are drawn as in Figs. (3,4 and 5) for the studied soils. These relations represented the hydraulic characteristics of soils in the two studied categories. From these Figures it is seen that the swelling of the soil affects the water characteristics of these soils type, where after swelling the diffusivity of the soils is increased especially at low water contents. The increasing percent of the difusivity is affected by the soil type and the location of each.

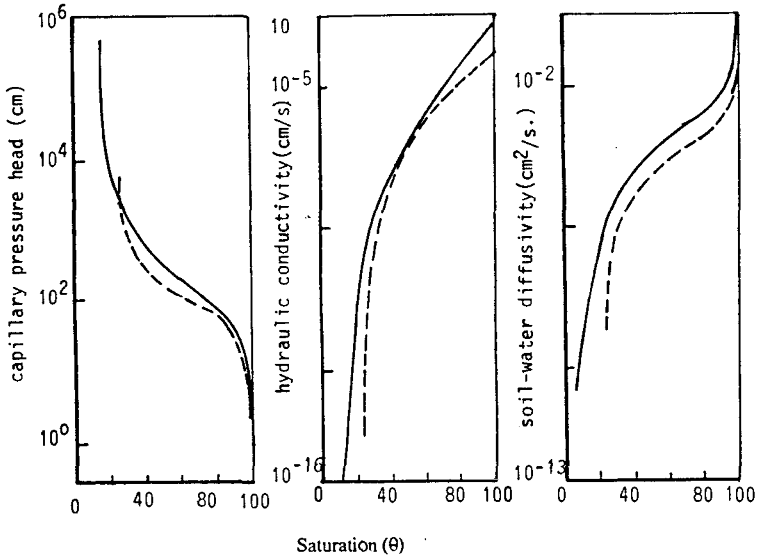
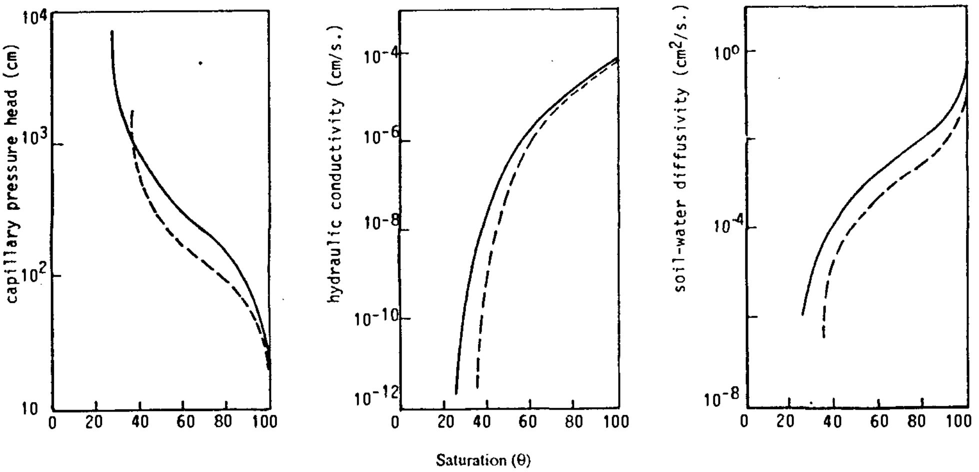


Fig. 3 Variation of soil-water characteristics with the saturation (New-Valley location) For the following conditions; Swelling was prevented ------------- and swilling was allowed



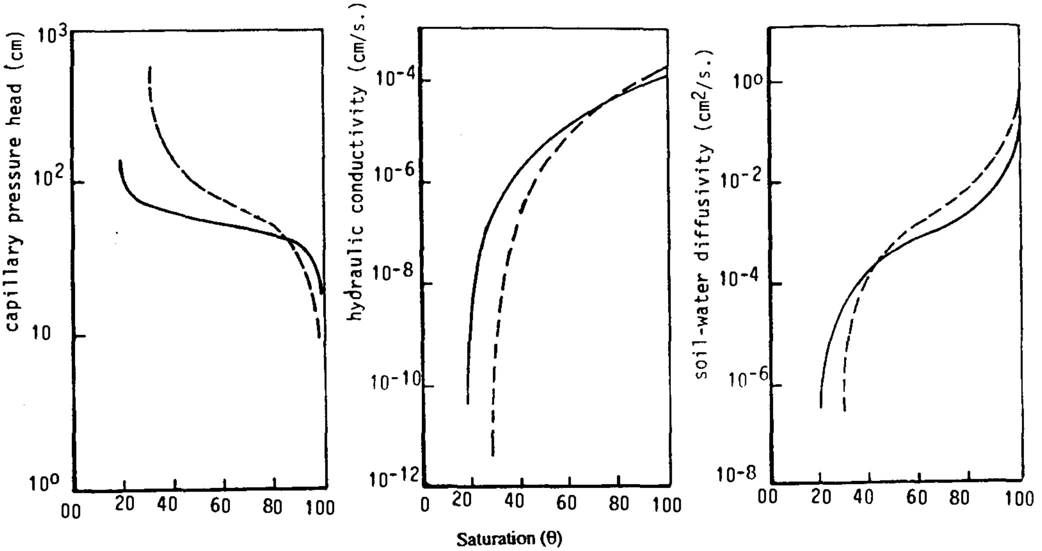


Fig. 5 Variation of soil-water characteristics with the saturation (Assiut location) For the followin conditions; Swelling was prevented ------------------- and swilling was allowe

Also, from these figures, the conductivity is increased for the same soil after the expansion and the rate of its increase is smaller at high water content. This may improve the cultivation characteristic of these soils in the unsaturated zone. For low water contents, the capillary rise is lower for the swelled soil than that for the same soil before its swelling, but it is higher at high water content From this result, it is noticed that, for the same soil type, the expansion of this soil increases the rise of the saturation from shallow water table and its percent. This means, in the case of shallow wate table, the swelling soil becomes more suitable for cultivation under sub-surface irrigation.

Looking to Fig.6, the reader can see the change of the dry density of swelling soil due to the chang in its water content for all the studied soils are arranged in groups according to their geographi locations. From this figure, the dry density of each soil decreases with the increase of the wate content. The decreasing rate of the dry density is rapid at low water contents, especially for the soil having low natural water content. This rate, is decreased gradually till the final water conten (plastic limit). The rapidly decrease of dry density at low water content may attributed to the rapi increase of the swelling percent of these soils in this stage till the specimen reached to the balanc condition and no more swelling will occur. The difference between the natural dry density and th final one depends on the natural water content in the site, where for the high natural water conten this difference becoming small. So, for dry and compacted swelling soils, one can predict that th swelling percent and consequently the swelling pressure is high and must be taken int consideration at the design and construction of the canal lining, pavement and irrigation and publi structures. In case of cultivating these soils, the improvement of soil-cultivation properties i expectant due to the increase of soil voids and the holding capacity.

Verification of the results: Three disturbed soil boxes having 500 X 250 mm in plan and 300 m height were prepared in Plexiglas poxes of 500 mm height. The soils in the three boxes wer identically compacted in 20 mm increment to 300 mm height. The soil was subjected to a consta zero-head of water at the bottom. The top surface of the soils were subjected to a stress of 1 kg/c on an area of 32 cm^2 to simulate a footing of a building and to prevent evaporation from this are

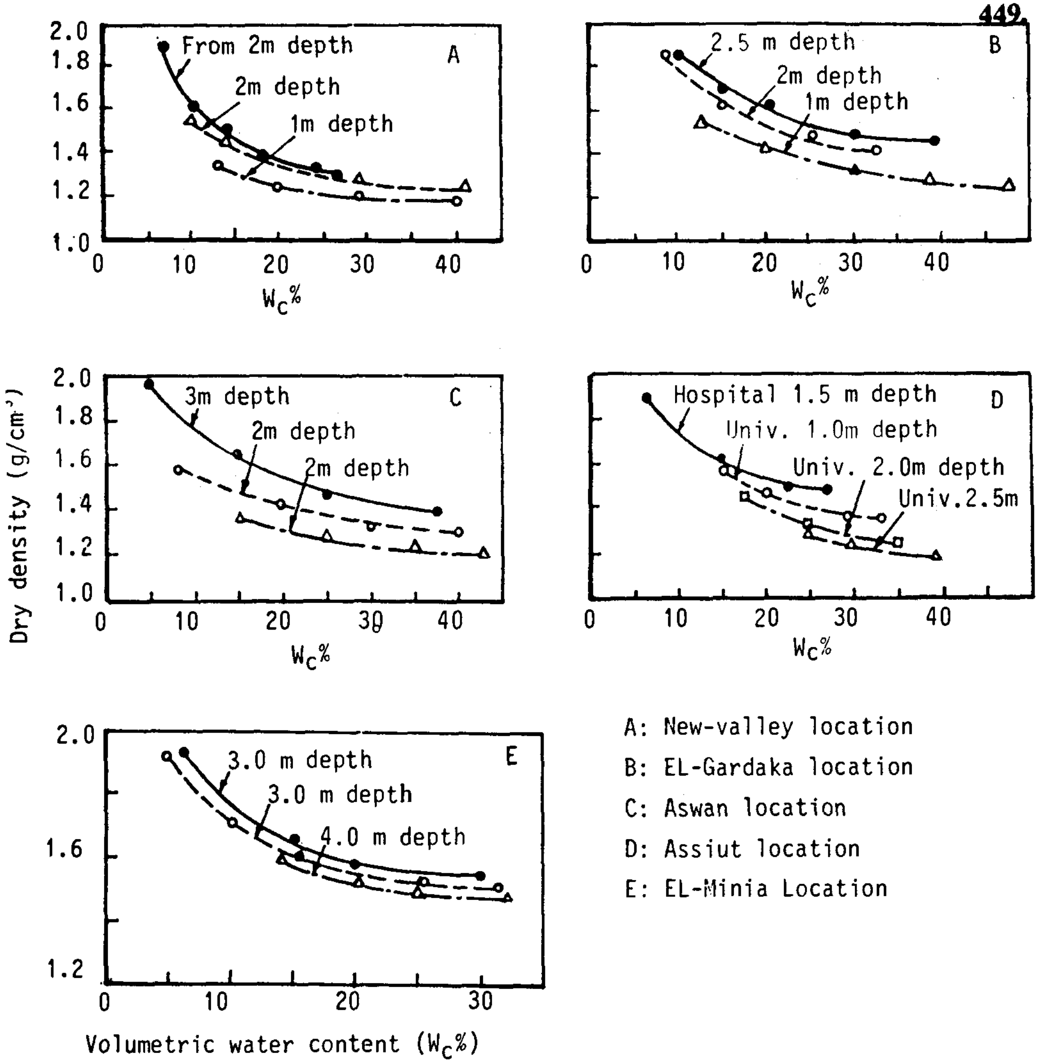


Fig. 6 Variation of the dry density with water content of the studied soils due to its swilling.

ikewise, after twelve and twenty days the other two boxes were broken respectively and both the noisture measurements and the vertical movements were measured as in Fig. 7. From this figure ne can observe that, for the first 4 days the rate of supplying water from the water table by the pen-side soil is slower than that under footing. This because the degree of swelling under footing s less and the capillary rise is high. Also, the soil is swelled in its two parts. After 12 days the welling is continued in the free soil part, but under the footing the soil has 7 mm settlement and till the increase of soil water content. The 12 days conditions are continued to 20 days but it is bserved that the top 5 cm of free surface soil has a declination of its water content, this may be due o the broken of the soil surface because of its swelling. Under the footing the water content is igher than the free surface soil. From these results, one can predict that, at shallow water table represents sub-surface irrigation), the total volume of water in swelling soil is high but its percent t the surface is low. Where in the case of swelling soil under footing the water content is high nder footing due to two reasons, the first is the absence of evaporation and the second is the soil till compacted and its water supply capacity still high. The second results from this example is the hange of soil behavior from swelling at low water content under the footing to settlement at high vater content. This behavior may cause a damage of any construction under the cyclic water

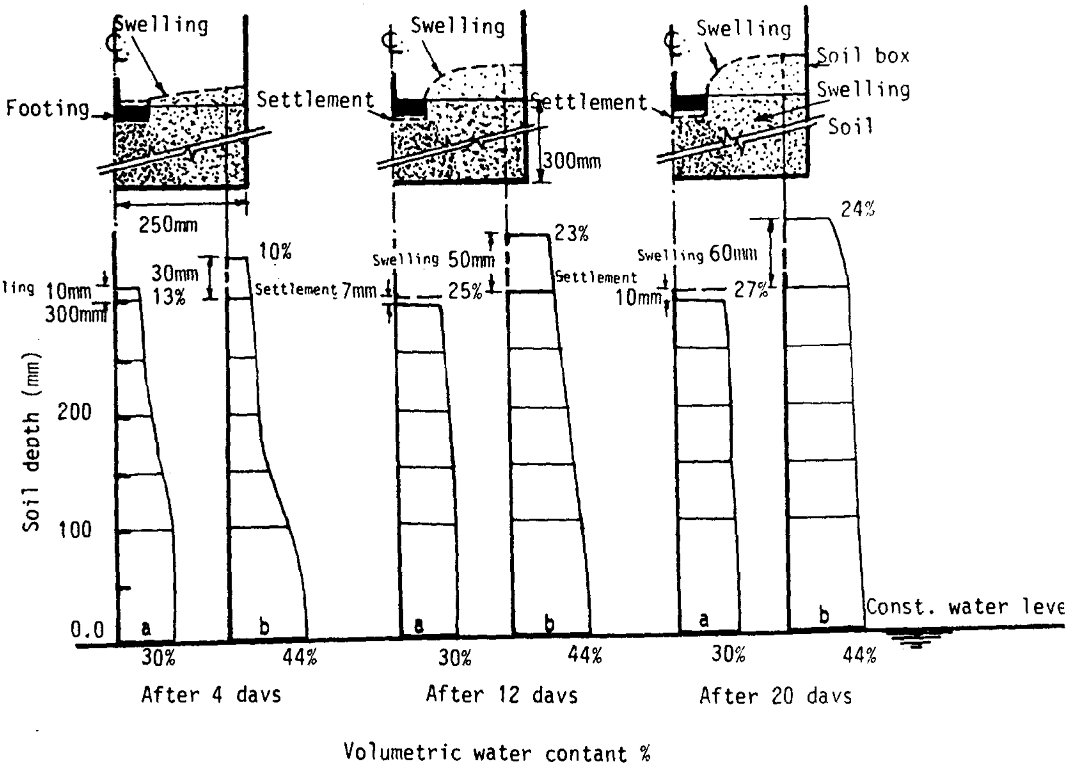


Fig. 7 The volumetric water content distribution through swelling soil (Assiut location) from sallow water table in case of; a) Under footing b) Soil has free surface.

6- CONCLUSIONS:

The findings from this study may have practical applications particularly where it is desirable to widened the use of swelling soil for new modern farm and cities. and the following conclusions may be drawn;

1- The physical properties change of natural soil due to its swelling has a major effect on its water characteristics.

2- The degree of compaction and the natural-initial water content of swelling soil affects the degree and the rate of its swelling.

3- The expansion of these soil due to its swelling improves the cultivation properties of these soils. that makes these soil more suitable for cultivation.

4- The predicted behavior of these type of soils (swelling) for low water content and (settlement) at high water content under footing built on these soils has a damage effect on the structures built on these soils.

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APPENDICES

Appendix 1: van-Genuchten model, 1980 of the soil-hydraulic characteristics.

The van-Genuchten model was adopted for presenting the hydraulic characteristics of the studied soils. This model can be written as follows:

$$S_e = \frac{\theta - \theta_d}{\theta_s - \vartheta_d} \qquad (0 \leq S_e \leq 1) \qquad (3)$$

$$S_e = \{ 1 + [\alpha\psi]^n \}^{-m} \qquad (\alpha > 0) \qquad (4)$$

$$n = \frac{1}{1 - m} \qquad (0 < m < 1, n > 1) \qquad (5)$$

$$C(\theta) = \alpha\,(n-1)\,(\theta_s - \theta_d)\,S_e^{1/m}\,(1 - S_e^{1/m})^m \qquad (6)$$

$$r(\theta) = S_e^{1/2}\{1 - (1 - S_e^{1/m})^m\}^2 \qquad (7)$$

where S_e is the effective saturation , θ_d and θ_s are the residual and saturated water content. and α, n and m are empirical parameters.

Appendix 2: The measured and estimated parameters:

The measured saturated hydraulic conductivity k_s, θ_d , θ_s and the porosity ϕ, and the estimated parameters α and m for each of the soil in the both studied categories are summaries in Table (1).

Table (1)

Soil location & its condition		$K_s(cm^2/s.)$	θ_d	θ_s	$\gamma_d(g/cm^3)$	$G_s(g/cm^3)$	ϕ	$\alpha(cm^{-1})$	m
Assiut	*	1.1E -4	0.18	0.99	1.48	2.7	0.46	0.0192	0/486
	**	1.83E-4	0.28	0.957	1.87	2.72	0.31	0.0165	0.679
Asswan	*	1.6E-4	0.25	0.99	1.31	2.72	0.518	0.006	0.492
	**	7.63E-5	0.35	0.99	1.91	2.72	0.3	0.01	0.6
New Valley	*	1.13E-3	0.145	0.98	1.18	2.7	0.53	0.09194	0.328
	**	1.65E-4	0.25	0.99	1.886	2.7	0.301	0.108	0.487

* Swelling was allowed ** Swelling was prevented