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EFFECT OF MOISTURE CONTENT ON HYDRAULIC AND PHYSICAL CHARACTERISTICS OF SWELLING SOIL

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ABSTRACT: Prediction of water amount and its movement through natural expansive soils due to ground water or water of irrigation is very important for engineers. This movement may affect drainage efficiency, pollutant movements, safety of constructions, canals lining and design of public and water structures. Present research is carried out to investigate; 1) Change of physical properties of swelling soils due to its saturation change. 2) Effect of soil swelling on the hydraulic characteristics of such type of soil. 3) Structural behavior of such soils under footings with different moisture contents. 4) The applicability of Genetic Algorithm (GA) technique for estimating two parameters included in van-Genuchten model. Unsaturated functions of soil are parameterized using van-Genuchten model 1980. Unsaturated flow model is solved numerically using the finite element technique. A practical technique for estimating the unsaturated hydraulic properties of the soil was developed on the basis of van-Genuchten model and Genetic Algorithm. These parameters are estimated through the inverse analysis of the transient change of saturation distribution along soil specimens which are extracted from different geographic locations in *Egypt*. The results showed that: i) Physical properties change of soil due to swelling has major effect on water movement through these soils and on their water holding capacities. ii) Such type of soils swells under the footing with low water contents and settlements with high ones, so this behavior is dangerous for the buildings constructed on it. iii) Swelling of these soils improves its cultivation characteristic, so these soils are more suitable for cultivation. iv) GA is a promising technique for parameters estimation in the inverse solution method.

Keywords: Swelling Soil, Unsaturated Hydraulic functions, Genetic Algorithm.

INTRODUCTION

Expansive soils are found in arid and semi-arid regions. Where as the development of land reclamation projects are increased due to the increase of economical growth, new cities and irrigation projects should be constructed on these soils. Damages of canal linings, retaining walls, bridge piers, pavements and other constructions due to swelling pressure of expansive soils lead to big economical losses. The expansive capacity of a soil depends upon type and amount of clay minerals and the exchange 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 clay mineral of other two groups swell considerably less. Many studies have been carried out on determining the excess of pressure on footings of structures due to the expansion of these soils and the percent of expansion[2, 3, 4]. Katti et al.[5] studied the depth effect on swelling in expansive clay. They concluded that no vertical swelling occurred below around 7.60 m depth. Wet-dry cycle effect on the design of piers was studied by Gromki[6].

There are essentially two techniques for estimating unsaturated hydraulic functions of soils. One is the direct measurement technique. This technique may time consuming, costly and is often limited to relatively narrow ranges of water content. Another technique is so called "Inverse solution". Efficiency of this solution to estimate unsaturated hydraulic functions was reported by some previous researches[7-12].

This solution involves analytical or numerical solution of the commonly used non linear Rechards' equation[13] for transient flow induced under some fixed initial and boundary conditions. Recently, several types of experiments were proposed by many researchers[7, 9, 10, 14] to generate unsaturated flow in soil specimens. Solution of Rechards' equation needs to define the unsaturated hydraulic functions. Some models parameterize these functions have been proposed for soil, among of them is the model of van-Genuchten[15]. The equations of van-Genuchten model are defined with four parameters. Two of them are measured experimentally while the others are estimated. For estimating these parameters by inverse solution technique, Genetic Algorithm (GA) has been frequently applied to solve science and engineering problems[16-19]. The objectives of this research are to investigate; 1) Change of physical properties of natural swelling soils due to its saturation change. 2) Effect of soil swelling on the hydraulic characteristics of such type of soils. 3) Structural behavior of such soils under footings with different moisture contents. 4) The applicability of GA technique for estimating two parameters included in van-Genuchten model.

METHODOLOGY

After Katti et al.[5] whome were studied the depth effect on soil swelling of expansive clay, present research investigates the hydraulic and physical characteristics of expansive soils from different locations in Egypt under two different treatments: *First*, soil specimens were prevented to swell; this treatment deals with the hydraulic characteristics of soil as it is in deep depth, while for the *second,* soil specimens were allowed to swell under different water contents. In the latter one, the relation between soil water-content and its dry density was predicted and soil water characteristics at the final stage of swelling process were predicted as well.

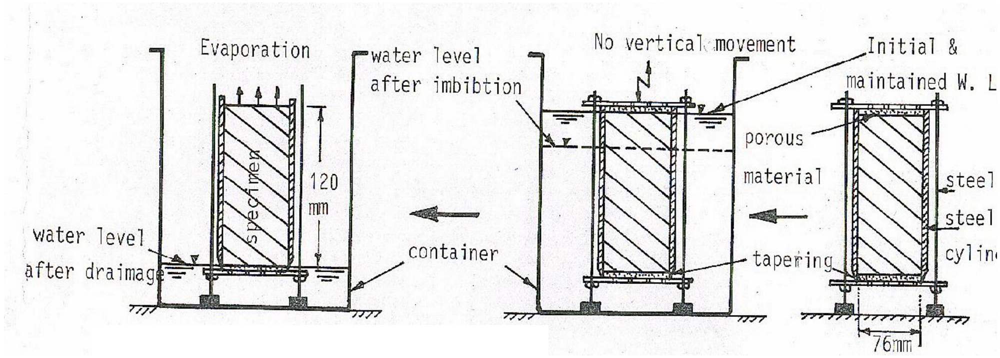
Transient Flow Induced by Evaporation

a) Soil specimens were prevented to swell: Undisturbed soil specimens were extracted, from different location in Egypt, using steel tubes having one edge tapering. Every tube has 76 mm internal diameter and 140 mm length. To prevent fine particles of soil from escaping out under swelling pressure, slices of porous stone having 13 mm thickness were placed at the top and at the bottom of each specimen. During the fully saturation process of the specimen, and to prevent its swelling up or down, two steel disks having some small holes, to allow for evaporation, were fixed in the upper and lower sides of the specimen with Steel rods (See Figure 1-a). The boundary condition at the bottom was zero potential and achieved by sealing the base of each specimen on a pane field with water and completely covered. The specimens were placed in a controlled temperature and humidity chamber. The evaporation from the surface was measured by a balance till it reached to steady condition. Table 1 shows the steady values of measured evaporation from each specimen. After that the final saturation distributions over the length of the specimens (θ_m) were measured gravimetrically. Both measurements were used in the inverse solution.

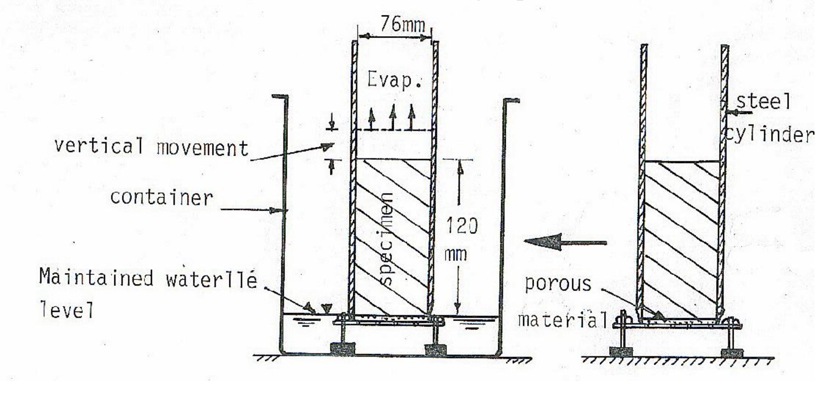
b) Soil specimens were allowed to swell: In this treatment, soil specimens were allowed to swell. So, soil specimens were prepared, by same way as in (a), but steel tubes have 200 mm length instead of 140mm to control soil swelling (see Fig. 1-b). To predict the relation between soil water content and its dry density, several different amount of water were added to the specimens and the new dry volumes were measured, consequently dry density was calculated for each specimen at corresponding water content. At the final stage of swelling of a specimen, steady evaporation rate was measured (see Table 1) and also final saturation distribution over specimen length(θ_m); both are used in the inverse solution.

Table 1 The measured steady evaporation from different soil specimens

Soil treatment	Climatic condition		Evaporation (mm/day) from specimen brought from		
	Temp. C^o	Humidity	Assiut Univ.	Aswan	New Valley
No swelling	≅ 27	≅ 40 %	1.20	1.10	1.05
With swelling	≅ 27	≅ 40 %	0.82	0.65	1.35



(a) First treatment (Swelling is prevented)



(b) Second Treatment (Swelling is allowed)

Fig. 1. Experimental Set Up.

THEORETICAL BACKGROUND

Basic Unsaturated Flow Equations

From the experimental program where unsaturated flow was passed through a soil specimen, the boundary conditions were defined (see Fig. 2). These boundary conditions are used in the inverse solution. When the hydraulic parameters defining the soil hydraulic functions are known, the vertical saturation can be calculated by solving the following Rechards' equation (13):

$$C(\theta)\frac{\partial h}{\partial t}=K(\theta)\frac{\partial^2 h}{\partial z^2}+E \tag{1}$$

$$h=z+\psi \tag{2}$$

Where, θ is saturation, C (θ) is specific moisture capacity of soils, K (θ) is the hydraulic conductivity, E is source or sink term, h hydraulic head, ψ is the capillary pressure and z is a height from reference level. Hydraulic functions were represented by van-Genuchten model (1980)15). The model can be written as:

$$\theta_e=\frac{\theta-\theta_r}{\theta_s-\theta_r} \qquad (0 \le \theta_{\mathrm{e}} \le 1) \tag{3}$$

$$\theta_e=\{1+[\alpha\psi]^n\}^{\text{-m}} \qquad (\alpha \rangle 0) \tag{4}$$

$$n=\frac{1}{1-m} \qquad (0 \langle \mathrm{m} \langle 1, \mathrm{n} \rangle 1) \tag{5}$$

$$C(\theta)=\frac{\mathrm{d}\psi}{\mathrm{d}\theta}=\alpha(\mathrm{n}-1)(\theta_s-\theta_{\mathrm{r}})\theta_{\mathrm{e}}^{1/\mathrm{m}}(1-\theta_{\mathrm{e}}^{1/\mathrm{m}})^m \tag{6}$$

$$K(\theta)=K_s\theta_e^{1/2}\{1-(1-\theta_e^{1/m})^m\}^2 \tag{7}$$

$$D(\theta)=K(\theta)\frac{d\theta}{d\psi}=K(\theta)/C(\theta) \tag{8}$$

Where, $\theta_r, \theta_s, \theta_e$ are residual, maximum and effective saturations respectively α , n and m are parameters defining the soil type and K_S is saturated hydraulic conductivity of the soil.

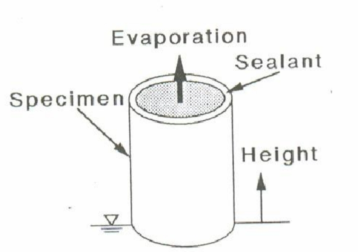


Fig. 2. Soil Specimen and Boundary Conditions.

Inverse Solution Technique

An inverse solution technique involves the indirect estimation of two parameters included in van-Genuchten model (α and m). Fig. 3 shows schematically the procedure of the inverse solution technique. In this procedure, the saturation distributions (θ_c) along the specimen of each soil are calculated on the basis of flow equation and simulating the experimental boundary condition after assuming the parameters (α and m). Then the measured saturation distribution (θ_m) and the calculated one (θ_c) are compared and the sum of square differences (SSD) is evaluated. If SSD is big, the parameters (α and m) are changed and θ_c and SSD are calculated again. Changes of the parameters were performed by GA technique. When SSD is less than the critical value (Cr), the iteration are stopped. In this study, Cr was taken the constant minimum value of SSD. The measured and estimated parameters of studied soils are shown in Table 2.

Table 2 Measured and Predicted Soil Parameters

Soil location& its treatment		*Measured*						*Estimated*	
		K_S *(cm/s)*	θ_s	θ_r	γ_d *(g/cm³)*	G_S *(g/cm³)*	*Porosity*	α *(cm⁻¹)*	*m*
Assiut	*No swell*	1.1E-4	0.99	0.28	1.87	2.72	0.31	0.0192	0.679
	Swelling	1.83E-4	0.96	0.18	1.48	2.7	0.46	0.0165	0.486
Aswan	*No swell*	7.63E-5	0.99	0.35	1.91	2.72	0.3	0.01	0.6
	Swelling	1.6E-4	0.99	0.25	1.31	2.72	0.518	0.006	0.492
New Valley	*No swell*	1.65E-4	0.99	0.25	1.886	2.7	0.301	0.108	0.487
	Swelling	1.13E-3	0.98	0.145	1.81	2.7	0.53	0.09194	0.328

Genetic Algorithm Application to Parameters Estimation

GA is based on the Darwinian-type survival of the fittest strategy and it operates through its genetic operators like selection, crossover and mutation to produce stronger individuals[19]. Each individual in the population represents a potential solution to problem (in this research, the combination of α and m) and is referred as a chromosome. Chromosone is assembled from a set of genes (substrings or bits in other words) that can be binary digits (the row of 0 and 1), integers or real numbers[20]. In this study, the 22 length of binary digits defined from real numbers of α and m were used. The fitness value (F) is a value related to the performance of the chromosome to the specific problem. In this research, F is defined as the value to minimize the SSD, that is;

$$F = \frac{1}{\sum_{t=1}^{n} [\theta_m(t) - \theta_c(t)]^2} = \frac{1}{SSD} \tag{9}$$

Where θ_m(t) and θ_c(t) are the measured and simulated saturation each time step as mention in Fig. 3. Population size (PS) is the number of individuals in a generation that are kept constant during GA calculation. Based on the previous GA studies[17-19] increasing the PS enables the GA to reach more points and thereby obtain better results is experienced. From the primary trials, the performance of GA with high PS gave slow convergence because it takes long time for optimizing of SSD. In this study the PS was decided to be 50 to get a fast calculation and good performance of GA.

Experiments

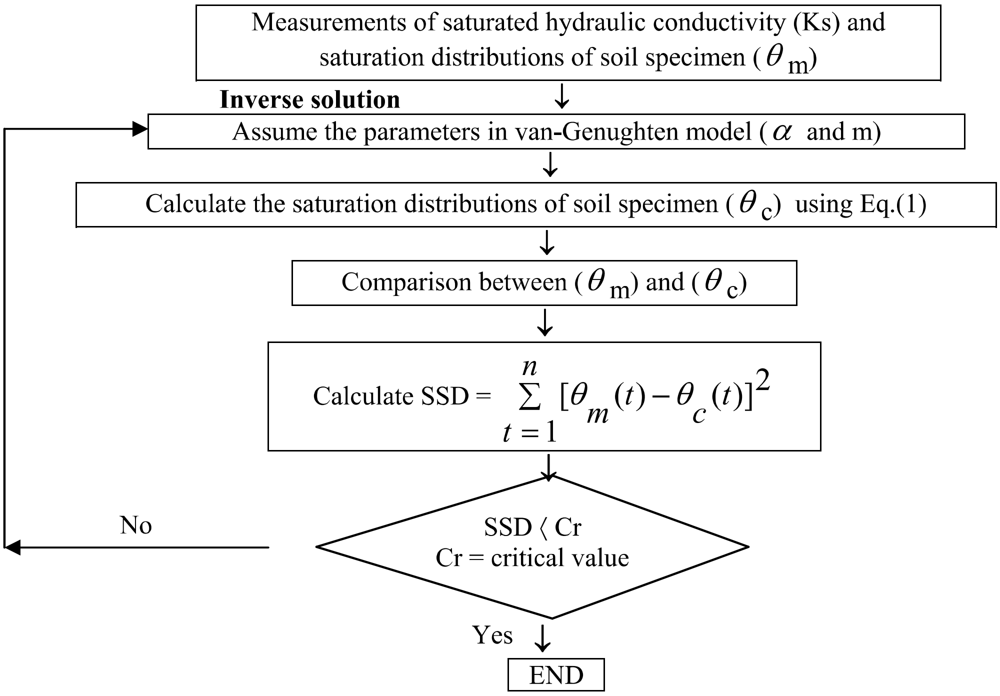


Fig. 3 . Procedure of the inverse solution technique.

The basic genetic operators; selection, crossover and mutation are the essential procedures for producing new and unique children. To ensure that the best chromosome is saved during the evolutionary process, the fitness-proportional or roulette wheel selection[20] is used in this study with elitism that is a process in which the best chromosome of each generation is carried over to the next generation. Various crossover techniques such as single-point crossover, two-point crossover and uniform crossover[21] have been proposed by previous researchers. Single-point crossover method is used here. Mutation action was carried out to randomly flip some of to bits (changing 0 to 1 or vise versa) in the chromosome. Mutation keeps the diversity in the genes of population and stops it from a premature convergence. Dandy et al.[22] suggested that a good performance of the GA may be obtained by using a high crossover probability i.e. 0.5 to 1.0 and a low mutation probability i.e. 0.001 to 0.05. However, these parameters of GA are also depending on the problem itself. Therefore, many trials of GA calculations for all soil specimens with different alternatives and certainly different GA parameters value for searching combination for the best of GA are examined in this study. After some trials of GA calculations, it's observed that the probability of crossover rate (Pc) is equal to 0.6 and the probability of mutation rate (Pm) is equal to 0.005 are gets the best SSD value and gave a good performance of GA for soil specimens. Fig. 4 displays the flow chart of calculation in which GA is used in the inverse solution.

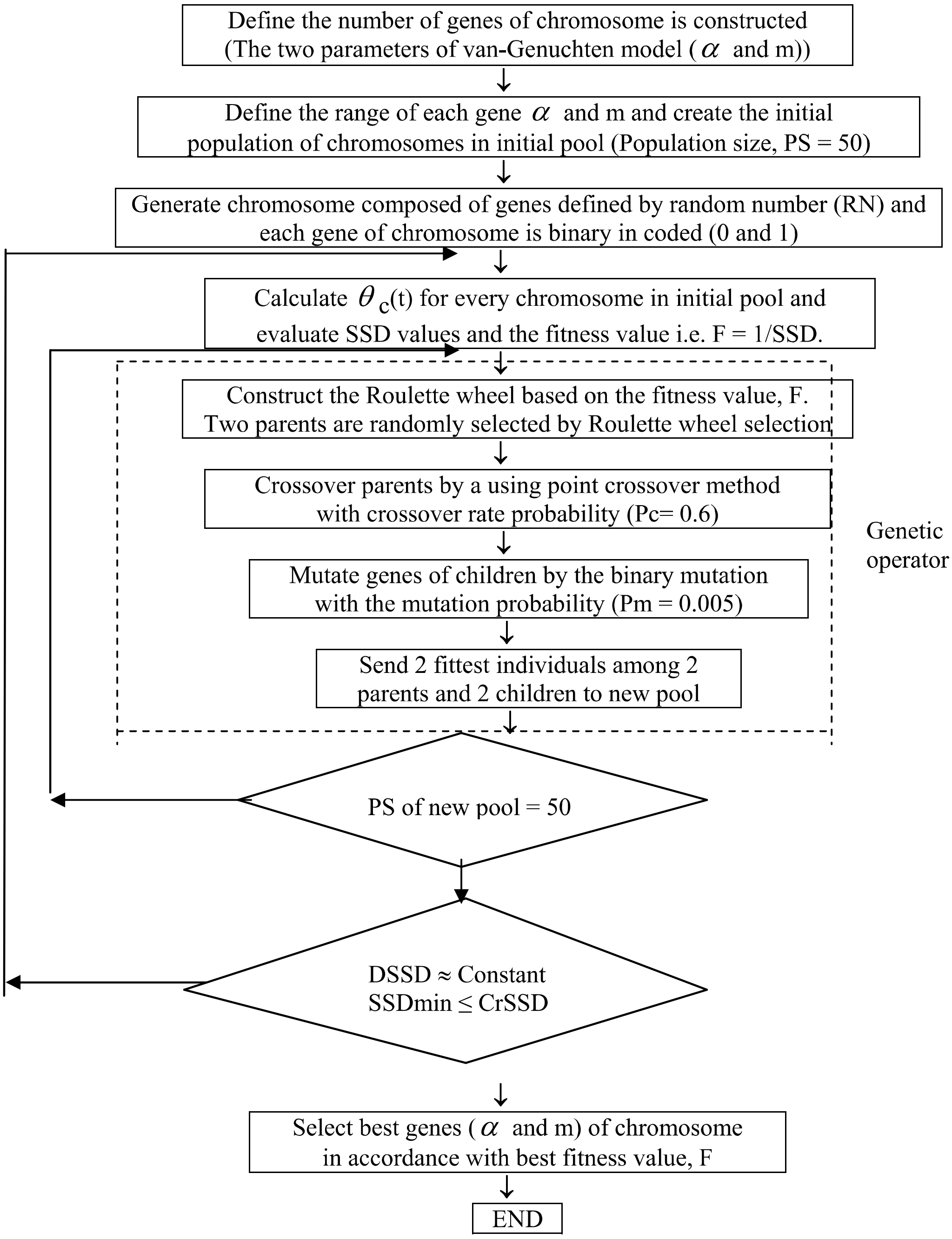


Fig. 4. Flow chart of GA application in the inverse solution technique.

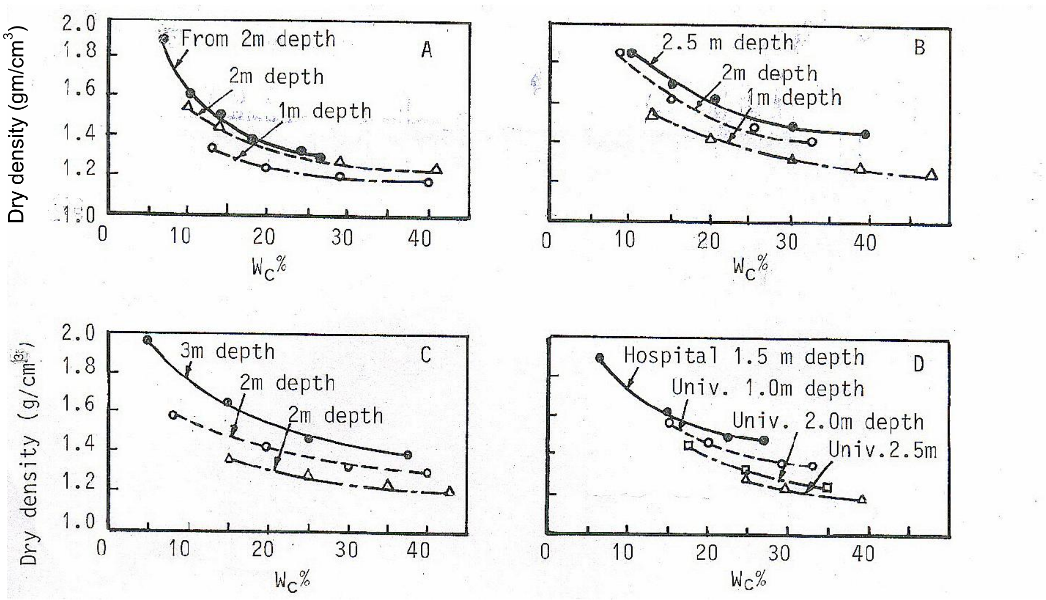
OBSERVATIONS

During the course of preparing the specimens and carrying out the experiments, it is observed that: 1) Water content at the higher part of specimens of second treatment (soil allowed to swell) is lower than that for those of first one (no swelling allowed). This may attributed to soil swelling increases pore space between soil particles and allow it to dry faster. 2) Rate of evaporation under controlling conditions of temperature (about $27C^{O}$) and air Humidity of 40 % is lower from specimens of second category than that from first one. This may due to low water content in second treatment, and water holding capacity of soil of first treatment is still higher. 3) Rate of vertical swelling is faster for low water contents and decreases with the increase of water content to a limit value, and then it changed to settlement near fully saturation. 4) The predicted total vertical swelling of soils having high in-situ water content is small.

RESULTS AND DISCUSSIONS

Experimental results for the effect of soil moisture contents on its physical characteristics are shown in Fig. 5. The figure shows the relation between water content and the corresponding dry density of the studied soils. Soil specimens were brought from different depths at New Valley, Hurgada, Aswan and Assiut locations. It is seen that dry density decreases with the increase of water content till a limit value and any further increase of water content corresponds no change in dry density. The rate of decreasing dry density is faster at low water contents. This may attributed to the rapid increase of soil swelling at low water contents. Specimen depth affects the behavior of decreasing dry density, where for shallow depth specimen, dry density decreases rabidly with water content change. This may because shallow depth specimens have low in-situ water contents and low overburden pressure. The difference between natural dry density and stable one (swelling is vanished) depends on natural in-situ water content. So, for dry and compacted soils, swelling percent and consequently swelling pressure is high and must be taken into consideration at designing and constructing canal lining, pavement and public structures. Cultivation properties of such soils may be improved due to the increase of void ratio. There are differences in the rate of change of dry density between the soils from different locations.

Van-Genuchten model parameters for unsaturated functions are estimated. Consequently, unsaturated hydraulic functions are defined and show in Figs. 6 to 8. Experiment on reminder soil type was failed. Each drawing represents one of soil functions under both rigid and swelling conditions of studied soils. Hydraulic characteristics of soil are affected by its swelling. For diffusivity and conductivity, they increase with swelling especially for low water contents. Percent of their increase may depend on soil location. Such increase in diffusivity and conductivity may improve cultivation characteristics of these soils. Also, capillary rise is higher in soils after swelling at high water contents, while it's lower for low water contents. This means for shallow water table expansion of soils increases the lifted up water and the soils become more suitable with sub-surface irrigation. Total capillary rise in non swelled soil is higher than that for swelled one.



Water content Wc%

A- New Valley location B- Hurgada location C- Aswan location D- Assiut location.

Fig. 5. Variation of dry density of soil versus water content

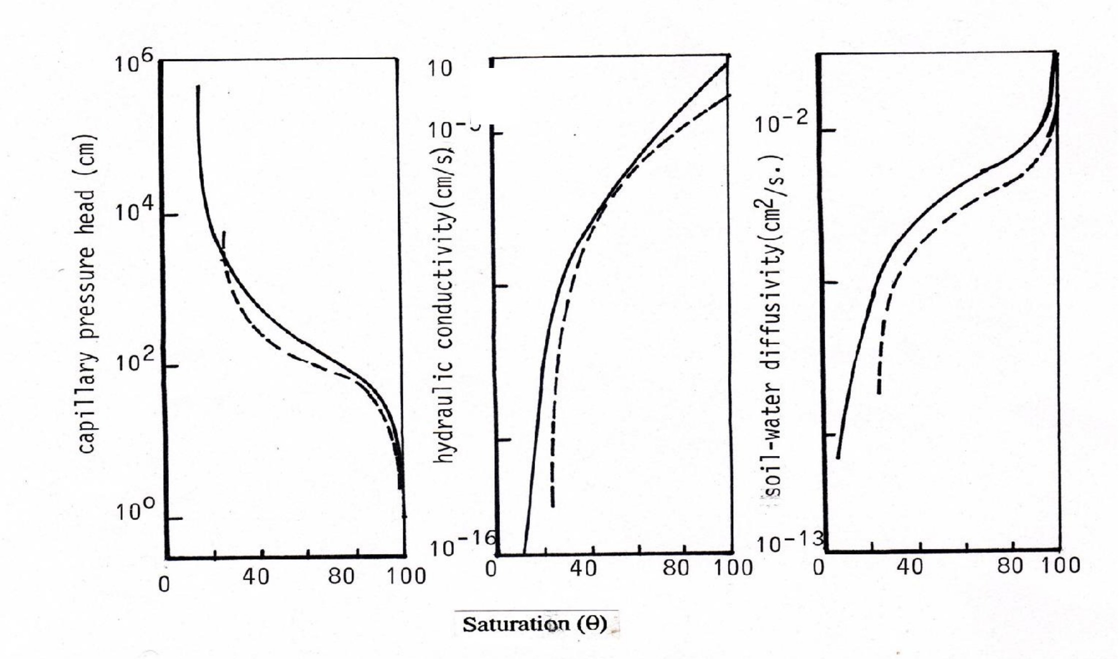


Fig.6. Soil-water characteristics for New-Valley location. (solid lines, swelling was allowed)

EXAMPLE VERIFICATION

Three Disturbed soil boxes having 500X250 mm in plan and 300 mm height were prepared from Assiut location in Plexiglas boxes of 500mm height. Soil in the three boxes were identically compacted in 20 mm increments to 300 mm height. Soil boxes were subjected to constant zero-head of water at the bottom. Top surfaces of soil in the three boxes were subjected to stress of 1 kg/cm^2 over a central area of 98 cm^2 to simulate a footing of structure and also to prevent evaporation from the 98 cm^2 area. The residual surrounding areas are free to evaporate and swell.

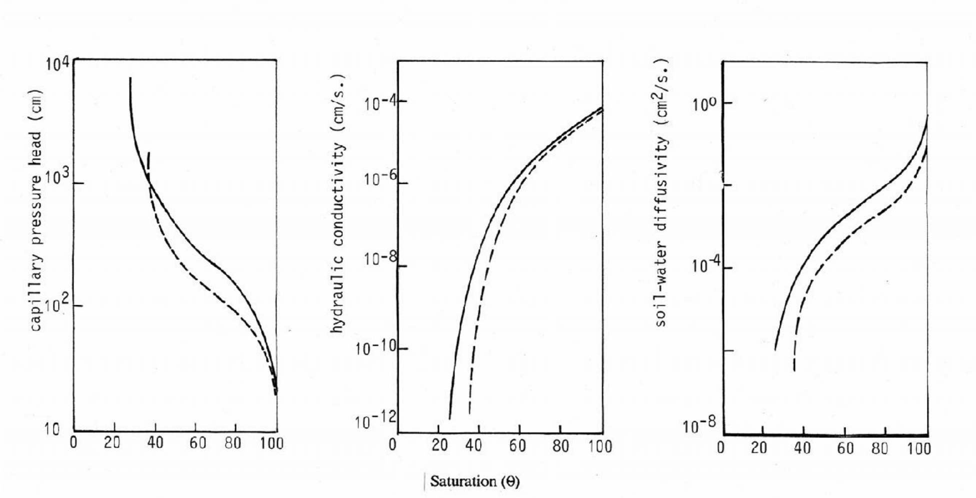


Fig. 7. Soil - water characteristics for Aswan location.(solid lines, swelling was allowed)

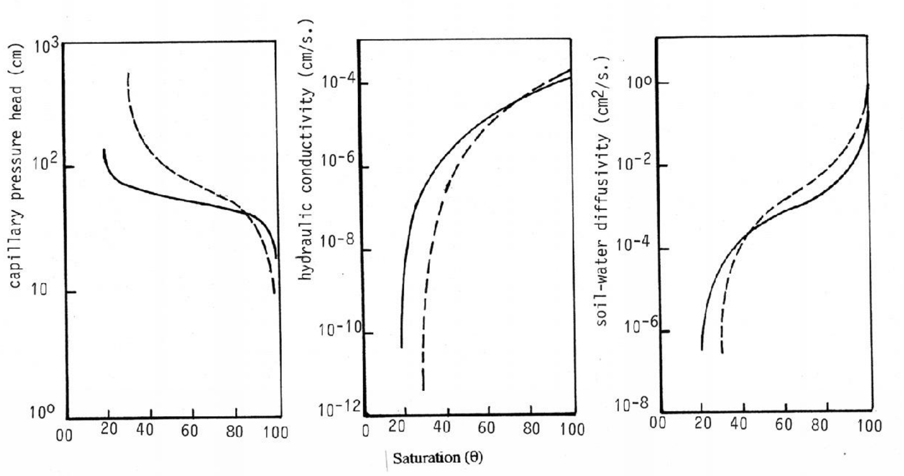
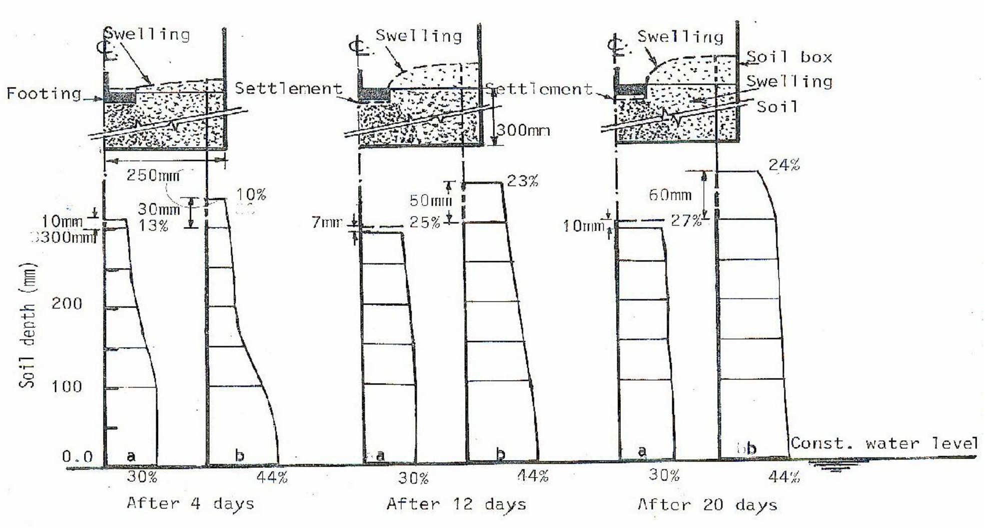


Fig. 8. Soil - water characteristics for Assiut location.(solid lines, swelling was allowed)

After four days and using one of soil boxes, moisture content distributions over soil depth were measured gravimetrically at footing centerline and at a distance 200 mm from it. Also, vertical swellings were measured at these locations. Likewise, after twelve and twenty days, both moisture content distributions and vertical swellings were measured at the identical locations respectively. The measurements are shown in Fig. 9.

From the figure, one can see soil swells under the footing with low water contents and settlements with higher ones and still in its progress in the outer footing area, so this behavior is very dangerous for the buildings constructed on it. Low surface water contents are observed in the outer footing soil area.



Volumetric water content %

a) Under footing b) Free soil surface

Fig. 9. Distribution of volumetric water content through swelling soil (Assiut location)

CONCLUSIONS

The findings from this paper may have a practical Utility and may be drawn as follows:

1. Physical properties change of soils due to swelling has major effect on water movement through these soils and on their water holding capacities.
2. Such type of soils swells under the footing with low water contents and settlements with high water contents, so this behavior is very dangerous for the buildings constructed on it.
3. Swelling of these soils improves its cultivation characteristics. So, these soils are more suitable for cultivation.
4. The GA is a promising technique for parameters estimation in the inverse solution method.

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