Indian Geotechnical Journal, 26 (2), 1996

Effect of Seasonal Moisture Change on Swelling Behaviour of Soil

Namir K.S. Al-Saoudi* and Orabi S. Al-Rawi†

Introduction

Several techniques have been proposed for evaluating the swelling ability of the expansive soil. The object of these techniques was to determine the swell potential and swell pressure that the soil may exhibit under an extreme condition of complete flooding. In the field, the extreme condition of flooding is rare, and the actual condition of moisture change that may occur is represented by cycles of wetting and drying leading to cycles of swelling and shrinkage of the soil. A limited number of researchers have studied the behaviour of expansive soils under wetting and drying cycles. (Ring, 1966; Chen, 1975; Popescu, 1980; Sridharan and Allam, 1981; Chen and Gui, 1987; Kanakapura and Giffered, 1987).

Ring (1966) examined the feasibility of several test procedures, Georgia method of testing, rapid cyclic wetting and drying test based on Porter's work in Texas and the linear shrinkage test. He concluded that the later test procedure was rapid and required a shorter testing time. It consists of determining the change in length (initial length – dried length) of a bar of soil placed in a linear shrinkage Teflon mold (200mm long with semi-circular cross section of 25.4mm diameter). Although this test is simple, but did not give the required number of wetting and drying cycles to reach the equilibrium condition.

Chen (1975), Chen and Gui (1987) carried out cycles of wetting and drying on samples of "claystone" soil. They concluded that signs of fatigue

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* Professor, Building and Construction Dept., University of Technology, Baghdad, Iraq.

† Research Student, Building and Construction Dept., University of Technology, Baghdad, Iraq.

were observed in each tested soil after each cycle of drying and wetting. Popescu (1980) demonstrated that cycles of wetting and drying carried out on an expansive soil with a crumb structure revealed a permanent swell, and that the swell per cycle accentuated after the first cycle.

Sridharan and Allam (1981) reported that repeated wetting and drying cycles produced a considerable potential strength accomplished by an increase in the stiffness of the soil fabric that revealed in a decrease in the compressibility of the soil fabric.

Kanakapura and Giffered (1987) showed that the swelling pattern and the number of cycles required to reach final equilibrium levels of swelling and shrinkage depend on the physical and environmental conditions. They also reported that the shrinkage of the soil in the field was rarely reaching its full value, and in most cases a partial shrinkage was noticed before the soil received the next rain or any other source of water.

In this paper an attempt was made to study the behaviour of an expansive soil under cycles of wetting and drying using both model and element tests.

Experimental Work

The Soil Used

The soil used was an artificially prepared soil, made by mixing natural soil, with commercial bentonite in a ratio of 7.5:1 by weight. This mixing ratio provided a soil with high expansive ability as shown in Table 1

Field Model 1

This field model was constructed previously (Mahmoud, 1990), where a bed of the same soil used in this work was compacted in a pit of dimensions 2.5m × 2.5m × 0.8m to initial placement conditions (d_1 = 14.81 kN/m^3 and w1=26.6%). The bed of soil was compacted in four sub-layers each 0.2m thick. Properly designed level marks were placed on the top and bottom of each sub-layer both outside and underneath the projection area of the footing.

Water Supply System

To simulate the moisture changes that may occur in the field, a special water supply system was designed and constructed to control the amount of rainfall automatically. The system consisted of source of water, system of pipes, automatically controlled supply apparatus and a square perforated channel fitted on the surrounding upper face of the model footing as shown

Table 1 Properties of the Soil Used

Soil Property	Natural Soil to Bentonite 7.5:1
Liquid limit, LL%	53
Plastic limit, PL%	19
Plasticity index, PI%	34
Shrinkage limit, SL%	16
Shrinkage ratio, SR	1.645
Linear shrinkage, LS%	17.8
Specific gravity, Gs	2.68
% Passing sieve No. 200	88.67
Clay content (% < 0.002 mm)	41
Silt content %	51
Sand content %	8
Max. dry unit weight d_{max} kN/m^3, (gm/cm^3)	16.52, (1.68)
Optimum moisture content %	17.3
Classification according to Unified classification system	CH

in Fig.1. Details of the system are give in Al Rawi, (1991).

Field Model 2

After gaining a sufficient experience in model testing and techniques from Model 1 a second model was constructed in the same site. The same soil used in Model 1 was removed, remixed and recompacted in the same pit, similar to Model 1. The initial placement condition were $d_I = 14.22$ kN/m^3, $W_I = 14\%$.

Element Tests

Element tests were performed to simulate the cyclic moisture changes that may occur in the field. Since there is no standard test procedure for the cyclic action , three test procedures were proposed. The tests were carried out on the same soil used in the field model. Samples were prepared by statically compacting the soil inside the oedometer rings to the same initial moisture content and initial dry unit weight of the model tests. The testing program is shown in Table 2.

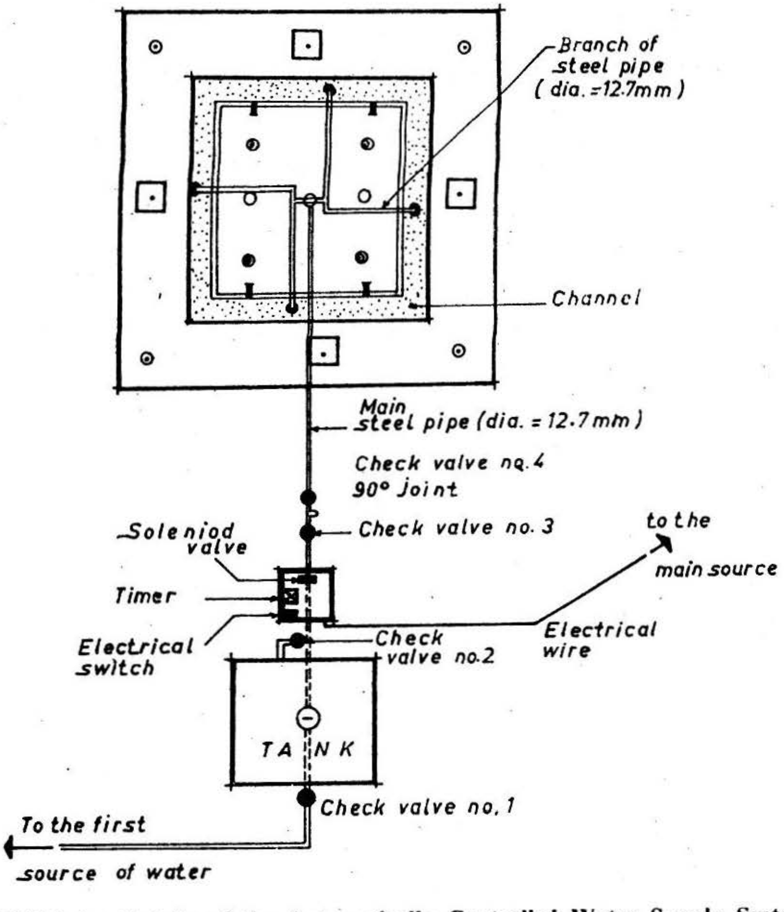

FIGURE 1 : Details of the Automatically Controlled Water Supply System

Test Procedure 1

The sample in the first half of the cycle was flooded and the amount of swell was recorded while in the second half of the cycle the sample was lifted from the cell and weighted, then returned back to the cell to complete another cycle, and so on. This test procedure provided a relationship between the amount of water absorbed by the soil and the amount of swell with respect of the initial moisture content and different time intervals. The results did not give any indication about the amount of shrinkage that may occur in the second half of the cycle. Thus a second test procedure was proposed.

Test Procedure 2

Similar to Test Procedure 1, the sample was removed after each wetting period immediately, weighed and then subjected to an air blower placed at different distances from the faces of the sample. After the drying period is completed, the sample was weighed and returned to the cell for another wetting cycle. The only disadvantage of this test procedure was that the amount of shrinkage can not be recorded during the drying period, thus a third test procedure was proposed.

Test Procedure 3

This test procedure was suggested by Kanakapura and Giffered (1987), to study the behaviour of samples under cycles of full swelling and partial shrinkage. Samples were first allowed for full swelling then followed by an air drying period. The second wetting cycle started after the samples, in the first

Table 2a Testing Program – Test Procedure 1

Sample No.	Wetting Period (min)	No. of Cycles
1	15	5
2	30	5
3	60	5
4	120	5

Table 2b Testing Program – Test Procedure 2

Sample No.	Wetting Period (min)	No. of Cycles	Drying Temperature °C
1	30	4	81
2	30	4	65
3	30	4	54
4	30	4	48

Table 2c Testing Program – Test Procedure 3

Sample No.	Wetting Period (min)	Shrinkage Period (min)	No. of Cycles
1	Full swelling	upto 25% shrinkage	up to equilibrium
2	Full swelling	upto 50% shrinkage	up to equilibrium
3	Full swelling	upto 75% shrinkage	up to equilibrium
4	Full swelling	upto full shrinkage	up to equilibrium

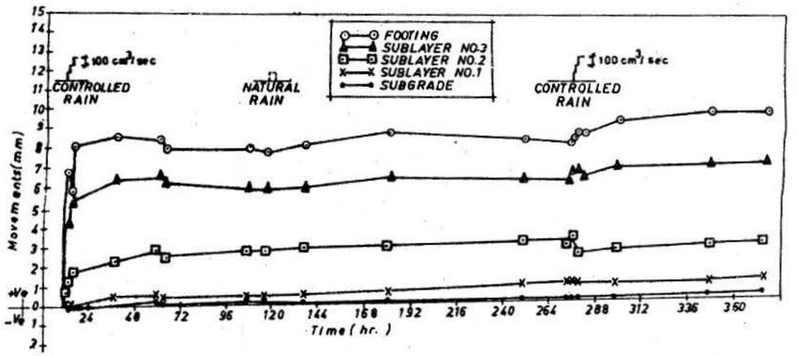

FIGURE 2 : Movements of the Loaded Sub-layers with the Time – Field Model 1

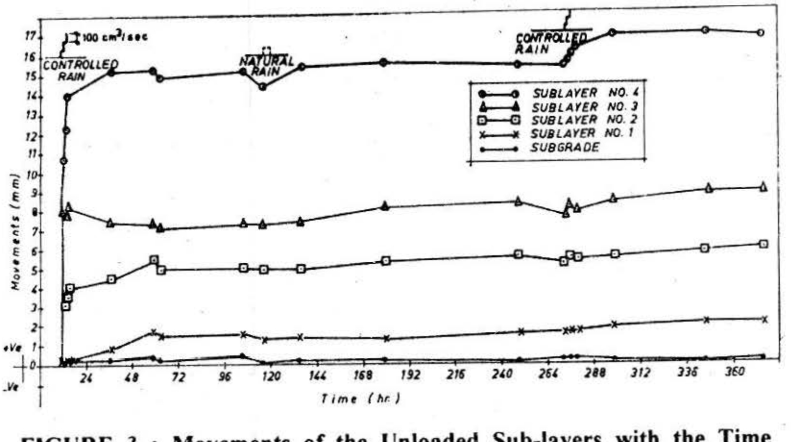

FIGURE 3 : Movements of the Unloaded Sub-layers with the Time – Field Model 1

drying period reached 25% , 50%, 75% and full shrinkage of the first swollen magnitude. The testing procedure continued until the expected equilibrium condition was achieved.

Presentation and Discussion of Results

Field Model 1

This model test started with the application of three wetting cycles of 100 cm^3/sec (controlled rain), the moments of the footing and the sub-layers underneath the footing and outside the projection area are presented in Figs. 2 and 3 respectively. Due to the presence of shrinkage cracks of different shapes, depths and sizes on the top surface of sub-layer 4, a rapid increase

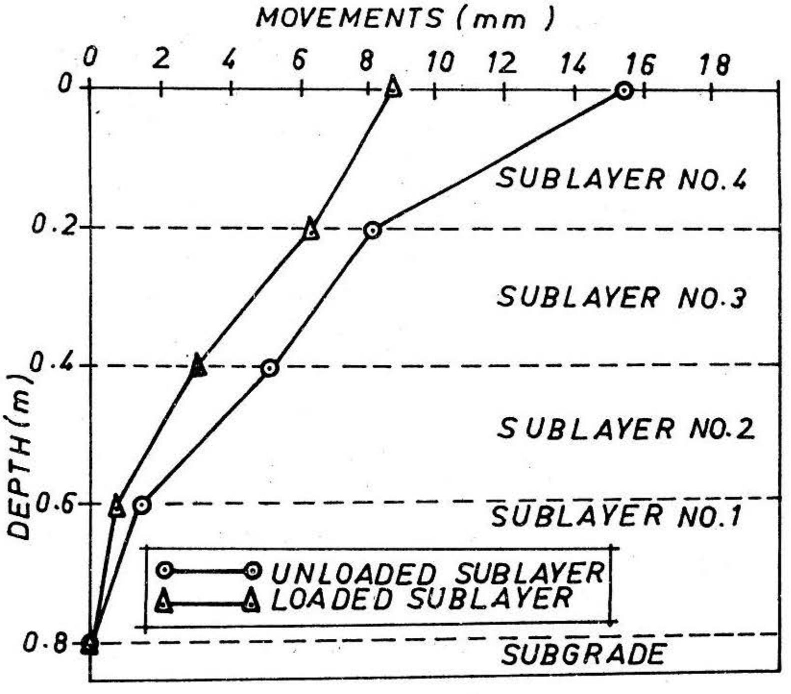

FIGURE 4a : Movements of the Sub-layers vs. Depth Relationship after 226 hrs. from the Starting of Test Field Model 1

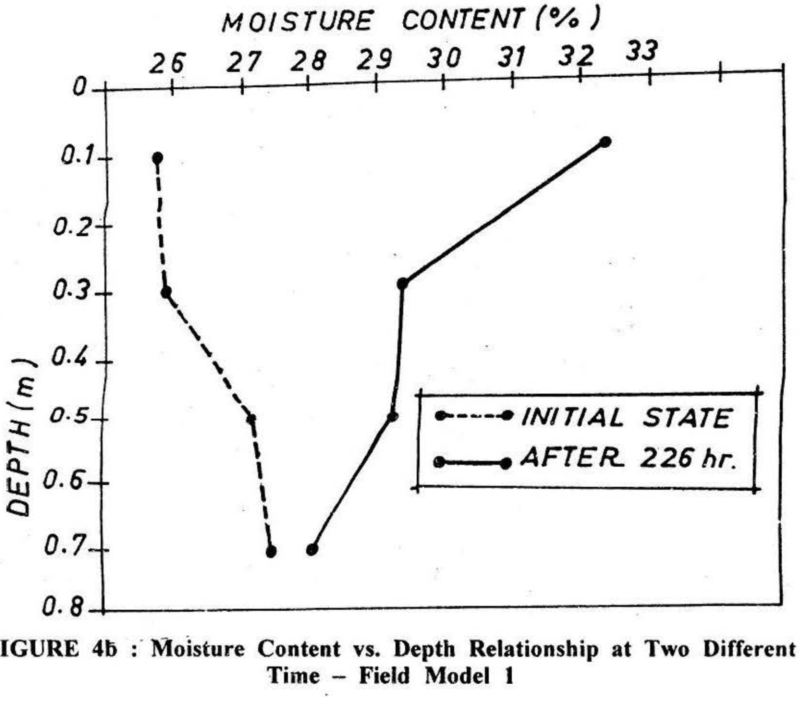

FIGURE 4b : Moisture Content vs. Depth Relationship at Two Different Time – Field Model 1

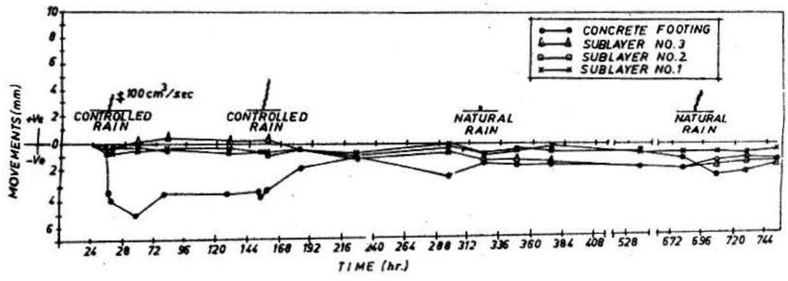

FIGURE 5 : Movements of the Loaded Sub-layers with the Time – Field Model 2

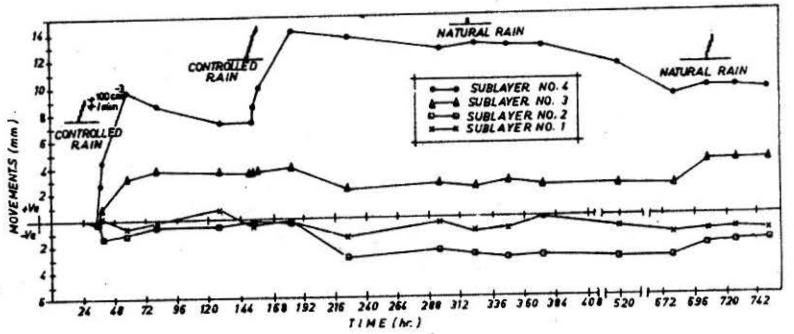

FIGURE 6 : Movements of the Unloaded Sub-layers with the Time – Field Model 2

in swell was observed in sub-layers 4, 3, 2 immediately after the application of the cyclic water, while sub-layer 1 showed a marginal increase in swell, this behaviour may be attributed to the rapid and quick absorption of water by the soil due to the presence of cracks. After the first controlled rain was finished, monitoring of the footing and level marks continued. The general trend showed a decrease in the rate of swell and equilibrium state was achieved approximately after 68 hours and afterwards the level marks showed a fair steady readings upto 100 hours where a natural rain took place for a period of 3.5 hours. A quick response to the natural rain was noticed in sub-layer 4 both outside and underneath the footing.

Before starting the second controlled cycles of rain, samples were taken for moisture content determination. The variation of the swell moments outside and underneath the footing with depth and the corresponding variation of moisture content with depth are shown in Figs. 4a and 4b respectively. Sub-layer 4 showed a higher increase in moisture content that reflected a higher swell movements, while the lower sub-layers showed a margin increased in moisture content and thus a lower swell movement.

The second controlled cyclic rain of 100 cm^3/sec started at 273 hours. Similar to the first controlled rain, the upper sub-layers showed a quick response to moisture change, but the rate of swell was less than the rate of swell recorded in the first controlled rain.

Field Model 2

Figures 5 and 6 show the variation of the movements of the footing and the level marks underneath the footing and outside the projection area. Similar to the Field Model 1, three cycles of controlled rain of 100 cm^3/sec were applied. The level marks of sub-layer 4 outside the footing area showed a rapid increase in swell, while its corresponding level mark underneath the footing area exhibited a rapid collapsible compression followed by a gradual swell which leveled off with time. This may be explained in terms of the collapse phenomenon that may occur in soil of low dry density under sudden increase in moisture content (Laing and Geoffery, 1969; Brackely, 1971; Singer and Santcs, 1987). Marginal Collapse occurred in sub-layers 1 and 2 both outside and underneath the footing area. After reaching the equilibrium level of swell in sub-layer 4 outside the loaded area, a gradual shrinkage was observed and continued at a lower rate with time. Shrinkage was not observed in other sub-layer neither outside nor underneath the footing area.

The second controlled rain started at 153 hours and consisted of six cycles of 100 cm^3/min. A rapid increase in swell was noticed in sub-layer 4 outside the footing area while the corresponding level mark underneath the footing area exhibited a slight collapse followed by a moderate increase in swell. The other sub-layers 3, 2 and 1 exhibited a collapsible behaviour followed by a slow rate of swell which levelled off gradually with time.

At 318 hours the first natural rain occurred for a period approximately 30 minutes, its effects on the level marks was negligible.

At 357 hours samples were taken outside the footing area for water content determination. The variation of moisture content with depth and the corresponding moments (heave or shrinkage) experienced by the soil sub-layers are shown in Figs. 7a and 7b. This figure indicated that the movements due to the change in moisture content were significant in sub-layers 4 and 3 while sub-layers 2 and 1 showed a slight change in movements.

During the period between 357 hours and 680 hours, the model footing was left under natural conditions, the daily inspection of the footing and the soil showed a gradual development of cracks on the surface of the soil

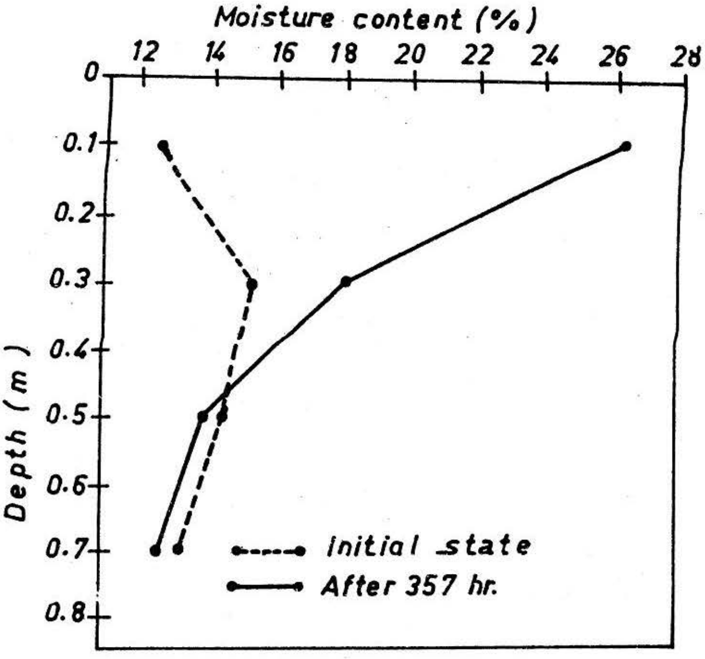

FIGURE 7a : Moisture Content vs. Depth Relationship at Two Different Times – Field Model 2

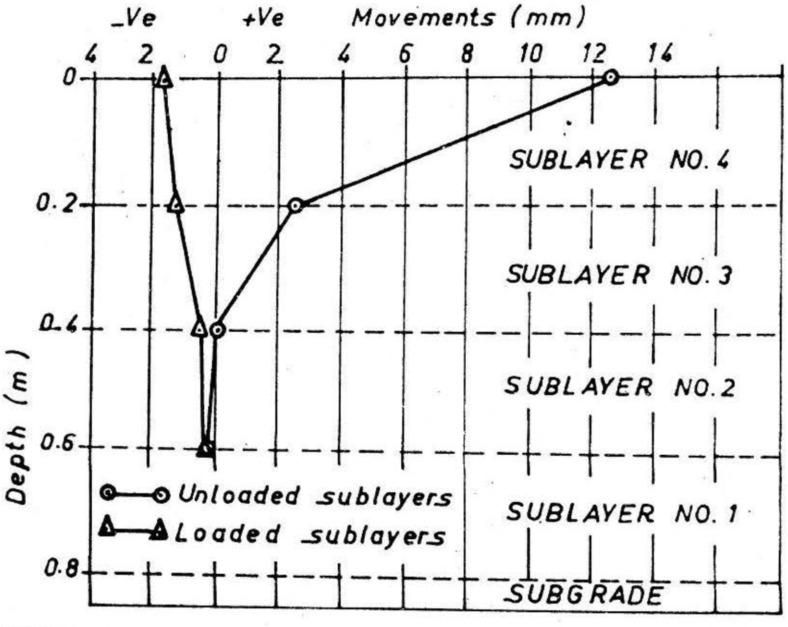

FIGURE 7b : Movements of the Sub-layers vs. Depth Relationship after 357 hrs. From the Starting Date of Testing Field Model 2

outside the footing area (sub-layer 4), this was accompanied by the shrinkage of the soil in sub-layer 4 as shown in Fig. 6. The other sub-layers did not respond to the drying process during that period of time.

A second natural rain occurred at 688 hours, its intensity was a higher than the first natural rain and lasted for a longer period. The level mark of sub-layers 3 and 4 exhibit a higher rate of heave compared with that recorded from the other sub-layers: It is also indicated that the natural cracks developed in sub-layer 4 slightly reduced its rate of swell but increased the rate of swell in sub-layer 3 which is located below the cracked zone. Similar conclusion was reported by Osman, (1987).

The rate of swell of shrinkage was plotted with time for the first and

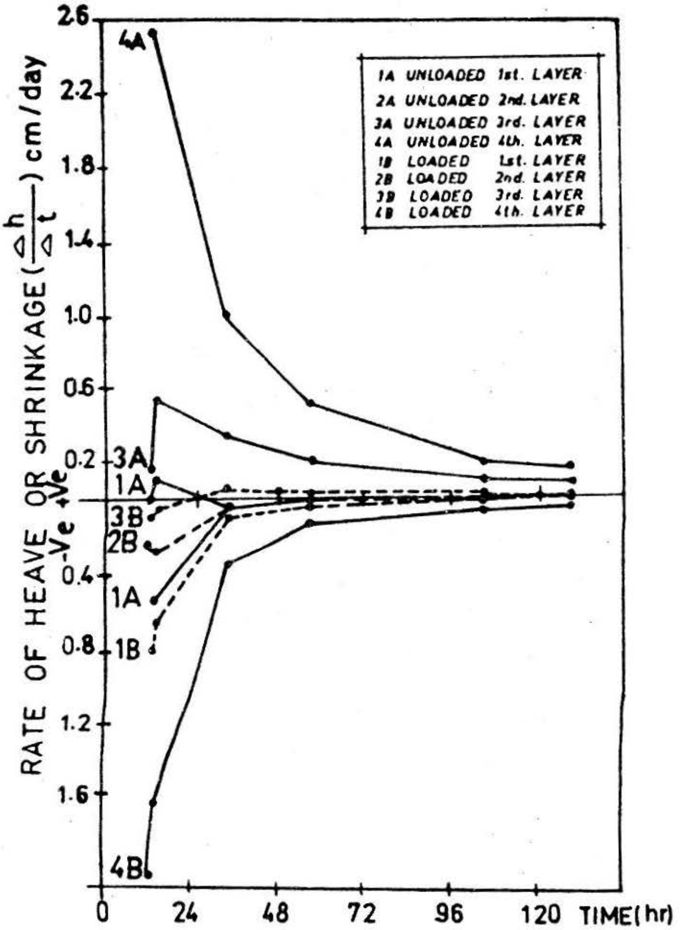

FIGURE 8 : Rate of Heave or Shrinkage with Time for Cycle 1 Subjected to Field Model 2

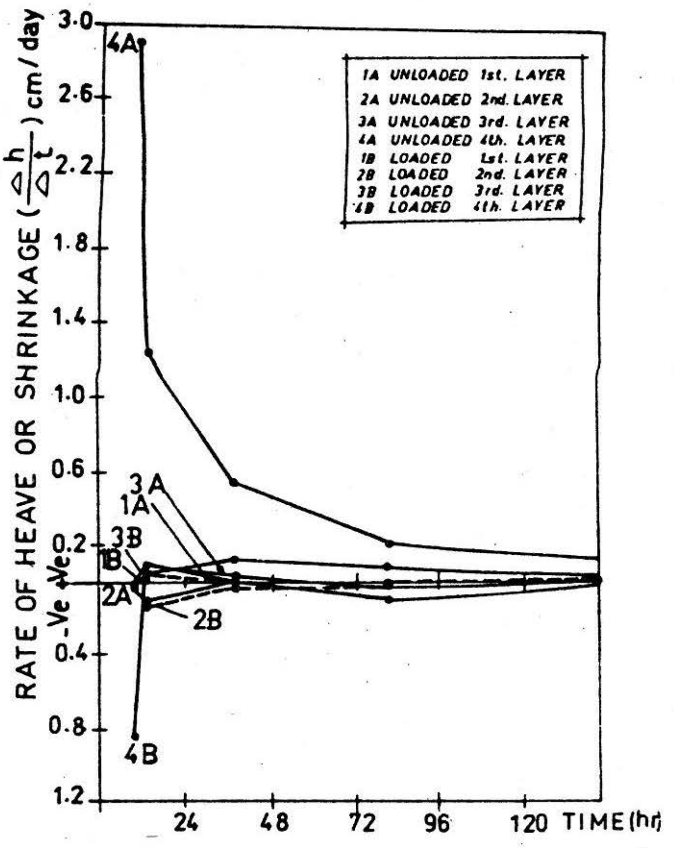

FIGURE 9 : Rate of Heave or Shrinkage with Time for Cycle 2 Subjected to Field Model 2

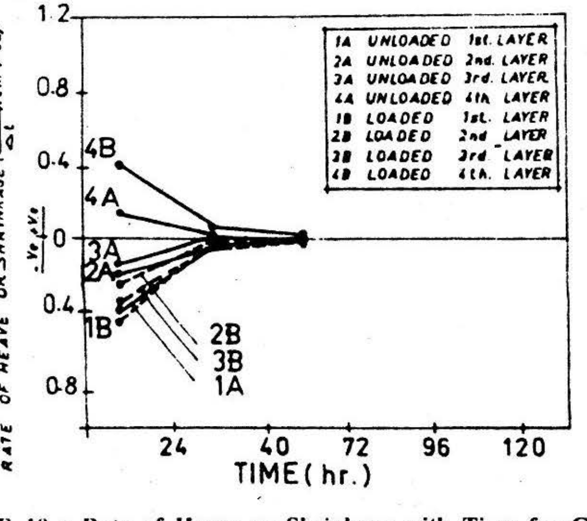

FIGURE 10 : Rate of Heave or Shrinkage with Time for Cycle 3 Subjected to Field Model 2

second controlled rains and also for the first natural rain as shown in Figs. 8 to 10 respectively. The rate of heave or shrinkage was defined as the change in height per unit time measured from beginning of the rain. In general the three figures showed that the rate of swell or shrinkage decreased with time and depth and was influenced by the intensity of rain and the time required for the water to be absorbed by the soil. It can also be seen that the rate of swell or shrinkage decreased with increasing number of rain cycles.

Element Test Results

Test Procedure 1

Five cycles were performed on each sample, the percent swell versus time for different wetting periods are shown in Figs. 11 to 14. In all the tests the major amount of swell was achieved in the first cycle irrespective of the period of the cycles. The amount of swell developed in the first cycle increased with the increase of the wetting period, thus allowing more time for the water to be absorbed.

The effect of number of cycles on the rate of swell (defined as the percent swell per wetting period) is shown in Fig. 15. The rate of swell decreased with increasing number of cycles for the different wetting periods, maximum and minimum rates were achieved after the first cycle for samples with 15 minutes and 120 minutes wetting periods respectively. The main defect of this test procedure was that it did not take into account the amount of shrinkage that may be experienced by the soil at the end of each wetting period.

Test Procedure 2

Four cycles of wetting and drying were performed on four samples. In these tests the cycle period was fixed to 30 minutes (15 minutes wetting followed by 15 minutes of air blower drying under elevated temperatures). The percent swell versus time for each test at various temperatures are shown in Figs. 16 to 19. In the first cycle, the amount of swell recorded for all the samples was approximately equal. The following drying period was performed at temperatures ranging from 81°C to 48°C. The first sample which was subjected to an air temperature of 81°C showed a sudden collapse immediately after the addition of water in the second cycle, this collapse behaviour was less significant in other samples subjected to lower elevated temperatures. Jennings and Burland (1962) explained this collapse behaviour to some kind of micro-shattering that may occur due to the sudden destroying of the bonds at higher elevated temperatures.

In general the percent swell and the rate of swell decreased with

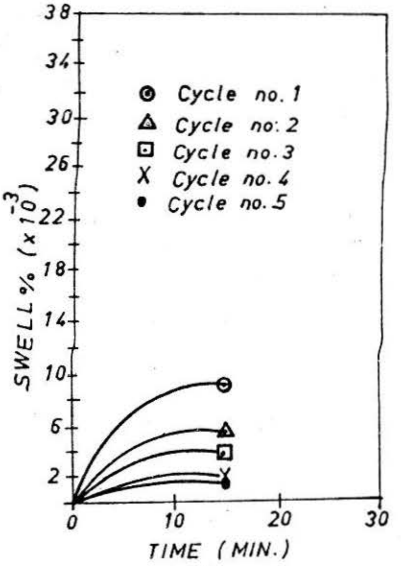

FIGURE 11 : Variation of Percent Swell vs. Time – Test Procedure 1 (Cycle of Wetting 15 min.)

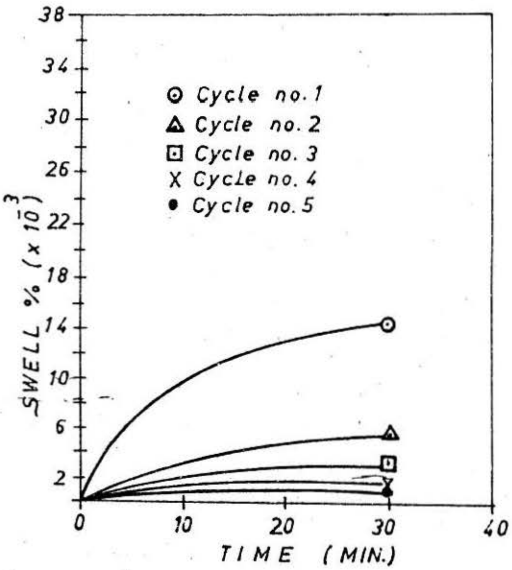

FIGURE 12 : Variation of Percent Swell vs. Time – Test Procedure 1 (Cycle of Wetting 30 min.)

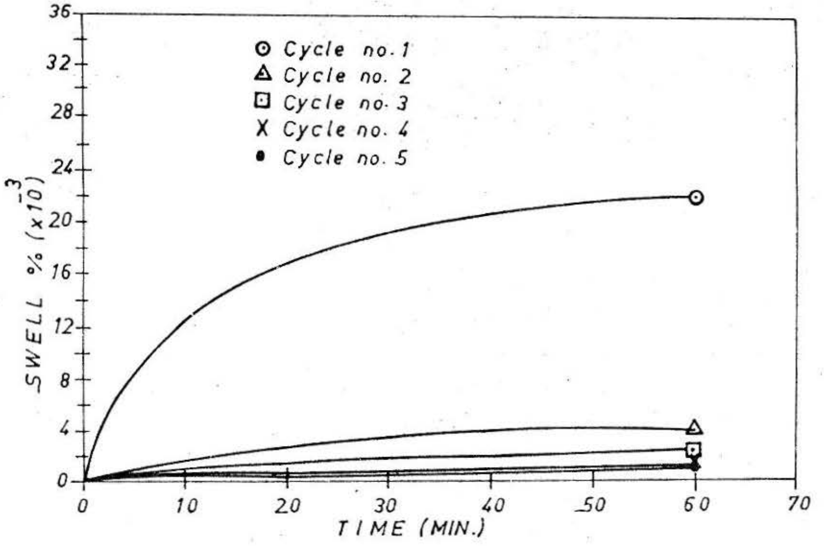

FIGURE 13 : Variation of Percent Swell vs. Time – Test Procedure 1 (Cycle of Wetting 60 min.)

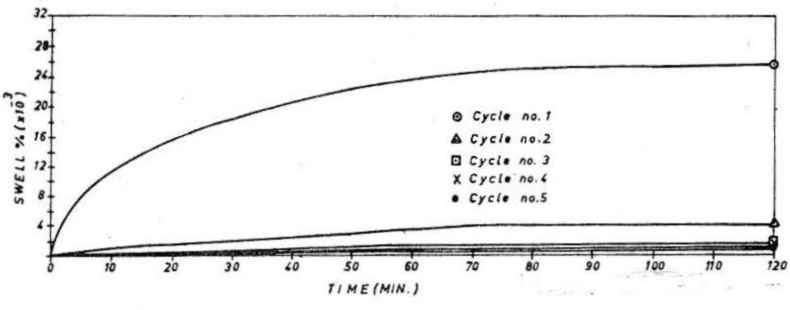

FIGURE 14 : Variation of Percent Swell vs. Time – Test Procedure 1 (Cycle of Wetting 120 min.)

decreasing temperature and increasing number of cycles.

Test Procedure 3

Four samples were tested in this series according to testing program in Table 2c. In the first cycle, the samples were allowed to full swelling in the wetting period followed by a drying period which was limited by the predetermined percent shrinkage. The percent shrinkage was taken as full shrinkage, 75% shrinkage, 50% shrinkage, and 25% shrinkage of the

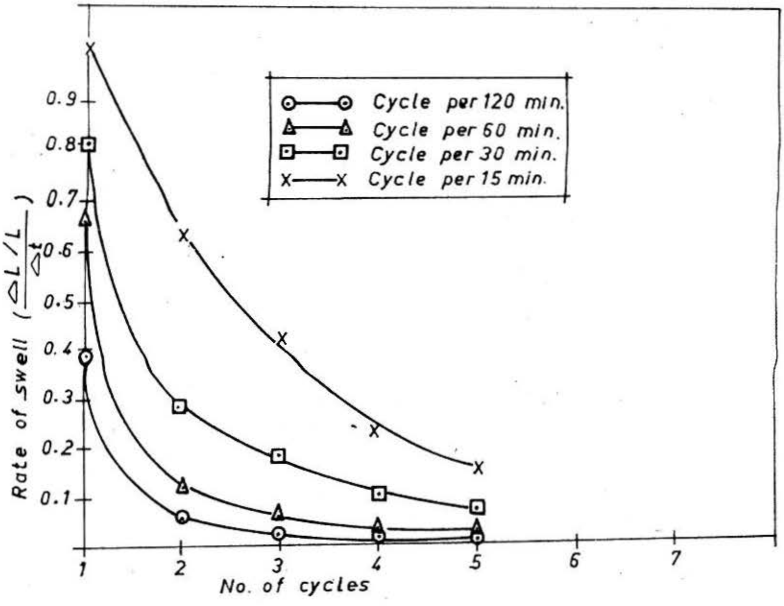

FIGURE 15 : Variation of Swell Rate vs. No. of Cycles – Test Procedure 1

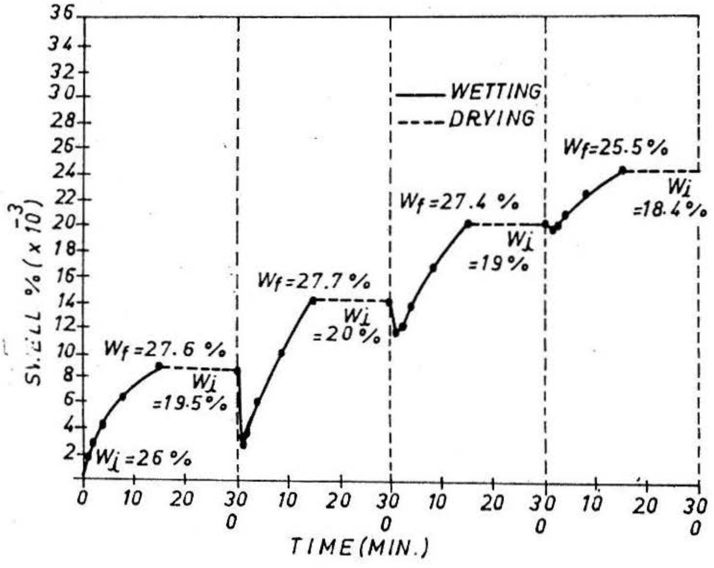

FIGURE 16 : Variation of Percent Swell vs. Time – Test Procedure 2

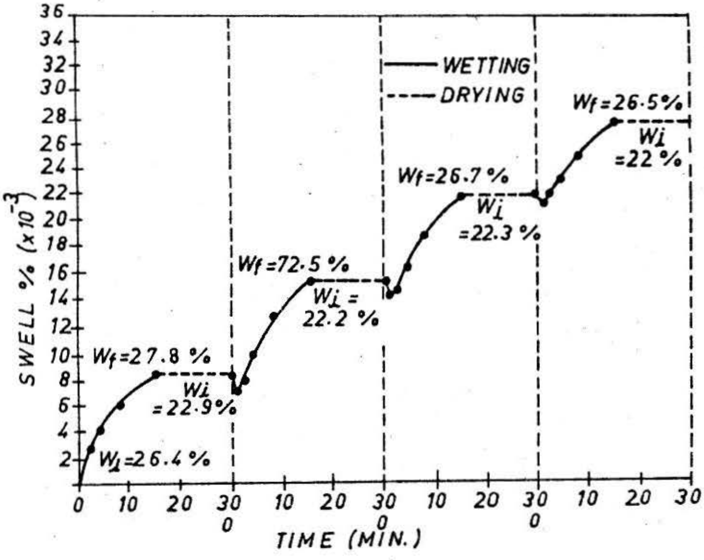

FIGURE 17 : Variation of Percent Swell vs. Time – Test Procedure 2

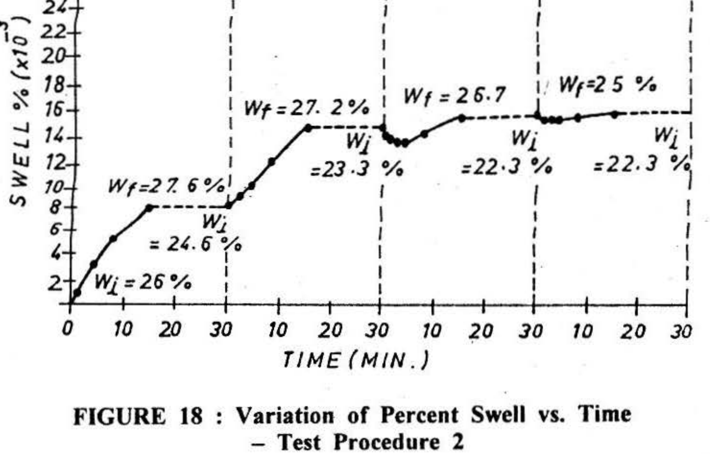

FIGURE 18 : Variation of Percent Swell vs. Time – Test Procedure 2

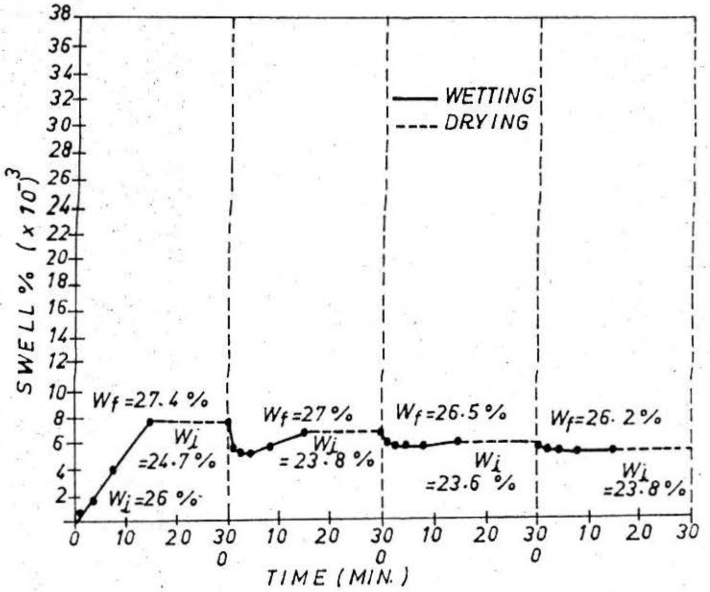

FIGURE 19 : Variation of Percent Swell vs. Time – Test Procedure 2

maximum amount of swell.

The height of the sample was plotted against the number of cycles in Fig. 20, the amount of swell reached its maximum value in the first cycle and then decreased with increasing number of cycles, also the number of cycles required to reach the final equilibrium levels of swell shrink increased with decreasing level of shrinkage.

The results obtained can be explained in terms of the fatigue phenomenon, where the soil may reach a fatigue level after several number of wetting and drying cycles, depending on the swell–shrink band experienced by the soil. Eventually the soil might reach a minimum ability of swell–shrink and probably levelled off (Chen, 1975).

Conclusions

Based on the results of the model tests and the element tests, the following points are drawn.

Model Tests

(i) The presence of cracks on the surface of the soil may reduce the amount

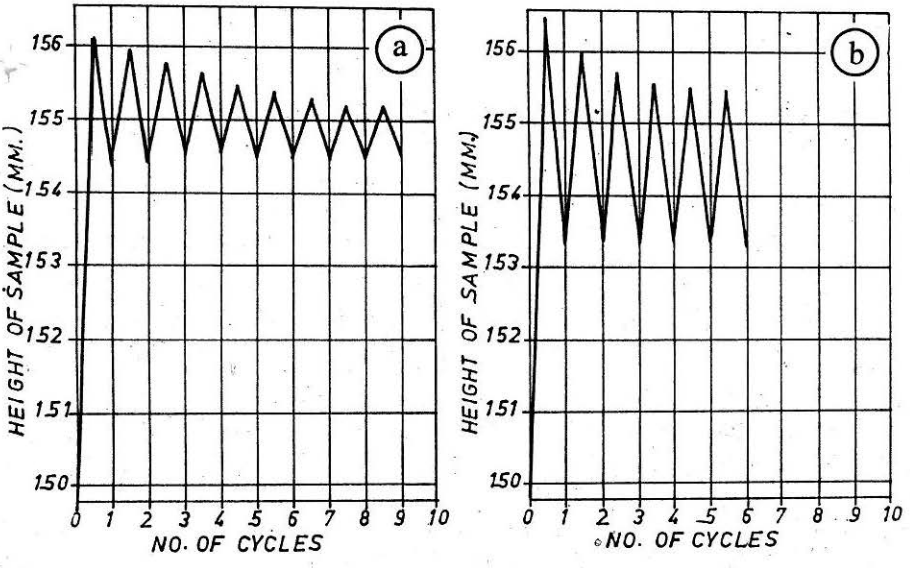

FIGURE 20 : Swell – Shrink Potential with Cycles of Full Swelling and Partial Shrinkage
(a) 25% Shrinkage
(b) 50% Shrinkage

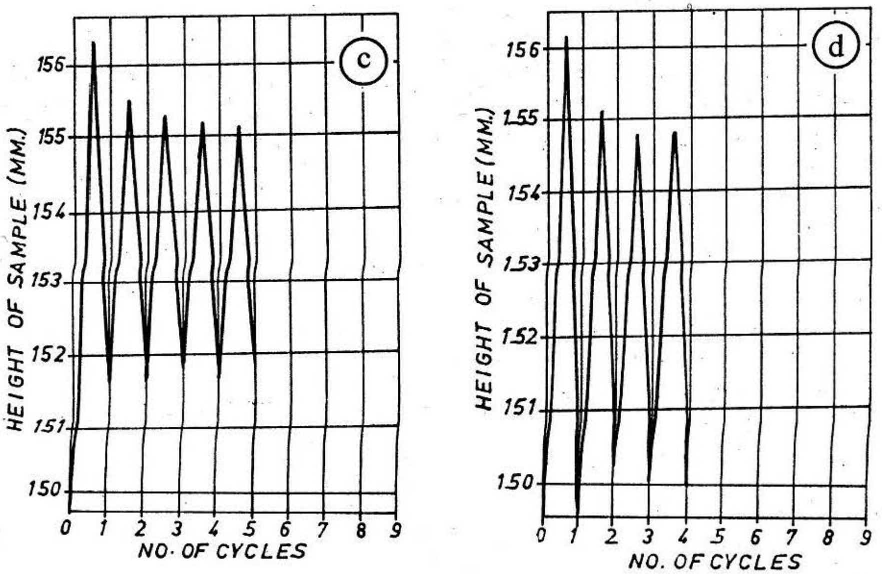

FIGURE 20 : Swell – Shrink Potential with Cycles of Full Swelling and Partial Shrinkage
(c) 75% Shrinkage
(d) Full Shrinkage

and rate of swell within the cracked zone, depending on the crack pattern, crack width and crack depth.

(ii) Lower initial placement conditions exhibit a collapse phenomenon under rapid moisture increase.

(iii) The rate of swell or shrink decreased with time and depth depending on the intensity of rain and the infiltration ability of the soil. In general a decrease in the swell–shrink ability was observed with increasing number of cycles.

Element Tests

(i) The amount and rate swell were influenced by the incremental amount of water absorption and the time period for each increment.

(ii) The rate of swell decreased with increasing number of wetting cycles and with increasing period of flooding.

(iii) In the wetting and drying tests (Test procedure 2), the soil exhibited a collapse phenomenon that increased with increasing drying temperature, and decreased with increasing number of cycles.

(iv) In swell-shrink tests (Test procedure 3), the number of cycles required to reach the equilibrium levels increased with decreasing percentage of partial shrinkage.

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