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Effect of Wetting and Drying Cycles on Swell/Collapse Behavior and Cracks of Fine – Grained Soils

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Abstract

Many of the soils undergo volumetric changes due to the change in the water content. Swell-shrink and collapse behavior of those soils affects the stress state in soil and the interacted structures. Shrinkage in the soil produce cracks of different patterns, and affects the swelling potential in next wetting cycle.

This study covers swelling and collapsing properties of four different soils from Mosul city. The changes in swelling and collapsing properties with respect to number of wetting and drying cycles have been investigated. Also, A shrinkage cracks have been studied with aid of digital image after each drying cycle. Number of segments and area of cracks calculated with aid of AutoCAD package.

Results indicated that, the collapse potential is influenced by soil type (soil composition) and applied loads. As the applied loads increase the collapse potential increases. For sandy soil the collapse potential decreased with increasing wetting and drying cycles, and for the clayey soils, swell potential decreased while collapse potential increased with these cycles. It has been shown that the cracks increase with wetting-drying cycles. Larger values of percent crack area to the initial sample area has been observed in the soil that contain more clay content than other types of soils.

Keywords: Swell Potential, Collapse Potential, Wetting and Drying Cycles, Cracks, Number of Segment.

تأثير دورات الترطيب والتجفيف على سلوك الانتفاخ/التداعي والتشققات للترب الناعمة

الخلاصة

يهدف هذا البحث إلى دراسة تأثير دورات الترطيب والتجفيف على سلوك الانتفاخ/التداعي والتشققات للترب الناعمة. تم اختيار أربعة أنواع من الترب الناعمة ومن مناطق مختلفة من مدينة الموصل، وتم دراسة تغاير كل من جهد الانتفاخ والتداعي لهذه الترب خلال دورات الترطيب والتجفيف. أيضاً تم متابعة وحساب التشققات المتكونة داخل نماذج هذه الترب وبعد كل دورة تجفيف. أظهرت النتائج أن نوع التربة ومقدار الحمل المسلط يؤثران وبشكل واضح على جهد التداعي، وأنه يزداد مع زيادة الأحمال المسلطة. كان مقدار جهد التداعي للتربة الرملية يقل مع زيادة دورات الترطيب والتجفيف ولم يلاحظ تكون أي تشققات داخل هذه النماذج خلال الدورات. بالنسبة للترب الطينية قل جهد الانتفاخ مع زيادة دورات الترطيب والتجفيف، في حين ازداد كل من جهد التداعي والتشققات مع هذه الدورات. أعطت نماذج التربة ذات المحتوى الطيني العالي أكبر مساحة للتشققات مقارنةً مع الترب الأخرى.

الكلمات الدالة: طاقة الدوامة، طاقة الانفجار، دورات الترطيب و التجفيف، تشققات، عدد القطع

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Introduction

Soils in natural condition undergo variation in behavior due to the cycles of wetting and dying, causing cyclic swelling/shrinkage and collapsing behaviors [1,2,3] . It is clearly evident that the swell/shrink and collapse or wet/dry cycles can change the clay structure in the soil leading to changes in soil behavior and causing some difficulties in engineering application [4].

Wetting and drying cycles associated with volume variations. These variation may be swell (increasing in volume) or collapse (sudden decreasing in volume) [5,6].

Swelling behavior of compacted cohesive soils depends on several factors such as: type and amount of clay mineral, moisture content, dry density and soil structure[7,8]. While the collapse behavior depends on percentage of fine particles (especially clay fraction), initial water content, initial dry density and the energy and process used in compaction[9,10].

The upward and downward movement (volume change) which occurs to the soil sample during wetting and drying cycles, leads to cracks formation. Soil cracks are the result of shrinkage and the low tensile strength. When there is water loss, suction forces increase until the tensile stress is equal to the cohesion forces, then cracks will be occur [11].

The aim of this study was to determine the factors such as number of wetting and drying cycles, loads and soil composition (soil type) affecting swelling/shrinkage, collapsing behavior as well as cracking of compacted soils.

Testing Program

Materials

Soil

Four soil samples from areas of Mosul city were selected for this study having different properties. Each soil had been used for engineering construction purposes in Mosul city. The sites were named Al-Gabat, Al-Salman, 2nd Qadisyah and Al-Sedeeq districts. For ease of reference, the four sites will be referred to as S1, S2, S3 and S4 for Al-Gabat, Al-Salman, 2nd Qadisyah and Al-Sedeeq respectively. All soil samples obtained from (0.5 – 1.0 m) below the ground surface. Some of the index properties and chemical tests of soils were listed in Table (1), using the relevant tests based on the ASTM standard.

Water

Tap water was used in the preparation of samples as well as in all the tests.

Sample Preparation

Bulk amount of soils were obtained from a depth (0.5 – 1.0 m) as mentioned previously, thereafter, oven dried for (2 days) at (60^0 C), mixed thoroughly and passed through a (# 4 sieve), and stored in plastic bags. A standard Proctor compaction (ASTM D-698) was selected in the preparation of soil samples. The required amount of water was added and thoroughly mixed to get a uniform moisture content.

It was then stored in sealed bags in order to avoid moisture losses and left at least (24 hours) as mellowing time, and to ensure a good homogenization of moisture content. After this curing period, mixture was compacted in a specific mold corresponding to the required tests.

To evaluate the swell and collapse tests, remolded samples were prepared by static compaction at rate (1.27 mm/min). The soil samples were compacted directly into Oedometer rings(75 mm in diameter and 19 mm in height) at their moisture represented the dry side of the standard compaction curve, corresponding to the (90 %) relative density from the maximum dry unit weight. Table (2) and Fig. (1) show the standard compaction curves of soils and the values of water content corresponding to (90 %) relative density from the maximum dry unit weight. After that, the compacted samples were placed in a consolidation cell between dry porous stones and subjected to initial vertical pressure of (6.9 kPa).

Swell/Collapse Measurement

The compacted soil samples were evaluated for their swell or collapse potentials at vertical stresses of (25, 50, 100 and 200 kPa) respectively. A separate sample was tested at each pressure. Thus, four samples were tested. Each sample was incrementally loaded to the desired pressure and soaked with tap water. After that, time–swell/collapse readings were continuously noted during the process. The final reading of dial gauge after (24 hours) was used to calculate the swell or collapse potential to allow for any residual swell or collapse of the sample. The swell or collapse potential was calculated from the equation:

$$\text{Swell/collapse Potential} = \frac{\pm \Delta e}{1 + e_{unsoaked}} \times 100 \quad \dots \quad (1)$$

Where Δe : represent the increase (for swelling condition) or decrease (for collapsing condition) in void ratio after (24 hours) of the sample on wetting under the desired pressures (25, 50, 100 and 200 kPa), and e_0 : is the void ratio of the unsoaked sample at that pressure. The term Δe assumes a positive sign when the sample swells, and a negative sign when the sample collapses.

Wetting/Drying Procedure.

The compacted samples were subjected to alternate wetting and drying cycles in Oedometer device. After calibration with initial pressure equal to (6.9 kPa), and the initial reading recorded to estimate the swell/collapse potential, the samples soaked with tap water at the desired pressure (25, 50, 100 and 200 kPa). The samples completed most of their swelling or collapsing (depend on the pressure value) in (60 – 120 min.). However, the soaking period was extended to (24 hours) to complete any residual swelling or collapsing. After (24 hours), final reading recorded, then the water siphoned from the Oedometer cell, and the sample kept into the cell at least for (2 hours) at room temperature ($25^0 \pm 2^0$ C), to keep it safe from any damage.

After that, the sample extruded from the cell and dried for (24 hours) at (60^0 C). Before starting the next cycle, the sample cooled at room temperature ($25^0 \pm 2^0$ C) for (1 hour), average height and diameter of samples were measured, and photo had been taken to estimate the cracks area. The sample was wetted for (24 hours), after that, this procedure was repeated as mentioned previously for vertical pressures of (25, 50, 100 and 200 kPa) respectively.

Cracks Measurement

To measure the cracks area that formed at the end of drying cycles, new technique was used. This technique was done by recording the cracks area using photographs to the soil samples, then calculating this area using the (Auto CAD 2007) computer program. A platform with a fixed digital camera having high accuracy (10.2 mega pixel) was oriented to obtain clear photographs having an even light distribution in order to measure the cracks as accurately as possible. The total surface area of both soil sample and the cracks was measured directly and accurately by using the previous program. The percentage of the crack area relating to the total surface area of the sample is obtained directly. This technique was found suitable for such measurements.

Results and Discussion

Swell/Collapse Behavior of Compacted Sample.

Figure (2) shows the swell /collapse potential of (S1, S2, S3 and S4) samples as a function of applied loads. The samples of (S1) marginally collapse below (25 kPa) and continued at other loads (50, 100 and 200 kPa). The other soils samples (S2, S3 and S4) showed different behavior below (25 kPa) as compared with (S1) samples. These samples exhibit swell (2, 3.7 and 5.1 %) for (S2, S3 and S4) samples respectively, at (25 kPa) and collapse at the higher loads, this manner may be due to more clay content. For all soils, the increasing in collapse potential of the samples with increasing loads is according to expectations.

Swell/Collapse Behavior of Samples Under Wetting and Drying Cycles.

Four cycles of wetting and drying where applied to the soils samples, and the effect of these cycles were shown in Fig. (3). This figure indicate that, there is a different behavior between (S1) samples and other soils samples (S2, S3 and S4) from the 1st cycle. For (S1) samples, cyclic wetting and drying increased the reduction in collapse potential from (4.9, 5.7, 6.5 and 7.0 %) for 1st cycle to (1.5, 2.3, 3.7 and 4.8 %) for 4th cycle at a vertical pressures (50, 100 and 200 kPa) respectively. This may be due to rearrangement of soil particles that have been occurred in each cycle, leading to more stable soil skeleton, consequently the collapse potential decreased. While for other soils samples (S2, S3 and S4), the cyclic wetting and drying increased the collapse potential. In general, they swells in the 1st cycle below (25 kPa), after that the collapse increased as the cycles increased. The (S2) samples gave large values of collapse potential than (S3 and S4) samples, this may be due to soils composition (i.e. clay, silt and sand). The collapse potential values at (200 kPa) and 4th cycle were (7.5, 7.3 and 7.1%) for (S2, S3 and S4) samples respectively.

Cracks Measurement

The area of cracks was measured after oven drying for each cycle using photographs by AutoCAD computer program as mentioned previously, and the results of the cracks area (CA) as a percentage of the initial surface area (ISA) have been tabulated in Table (3).

The measured area of cracks represents the area of the surface only, because not all of the cracks are generated to the full depth of the sample. It worth mentioning that, the (S1) samples have been no visible cracks, because of the low plasticity of this soil, low volumetric shrinkage and low clay content. The other soils samples (S2, S3 and S4 samples) that have sufficient plasticity and clay content, contained cracks because even a small volumetric shrinkage is likely to result in the formation of some cracks.

The results in Table (3) shows that, the crack area in all samples increased after the first cycle of wetting and drying. The samples of (S4) gave a large values of (CA / ISA) than the other two (i.e. S2 and S3), because this soil is more plastic with more clay content than others. During the wetting and drying cycles, cracks in all samples firstly started at the contact point between the soil and the metal ring sides. This may indicate that, the adhesion between the soil and the ring is less than soil cohesion. So, during the wetting, the cracks are not closed or close only on the surface. However, the trace of the crack (especially the relatively large crack) had clearly remained and it looked like grooves of different sizes in the upper part of the sample. Finally, from the findings of cracking behavior during cyclic wetting and drying all the tested samples showed a continuous increase in crack number with the cycles leading to the destruction of big fragments (segments) into smaller portions. The results of the number of segments among cracks (NOS) are shown in Table (3).

Classification of Swell and Collapse Potentials.

Table (4) classifies the severity of collapse of the soils samples at (100 kPa) vertical pressure as compacted with wetting/drying states according to Fookes (1990) classification. Data in this table shows that, the wetting and drying cycles, in general, have a stronger influence on collapse potential, especially of the (S2 and S3) samples. Consequently, soil samples that classify as moderately troublesome samples in the compacted state, classify as troublesome samples at wetting/drying state. The collapse potential of (S1 and S4) samples showed a slight variation in their values, thus the classification of these samples was as moderately troublesome, and remained constant after (4) cycles of wetting and drying.

Conclusions

1. Wetting and drying cycles increases the collapse tendency for clayey soils, while reduces collapse tendency for silty or sandy soils.
2. Wetting and drying cycles reduces the degree of expansiveness of clayey soils.
3. cracks area and number of segments amongst cracks increased as the wetting and drying increased.
4. As the applied vertical pressures increased the cracks area increase.
5. Auto CAD computer program can be used with good accuracy for crack area measurement, further more, it can be considered as a simple and rapid method than graphical method.

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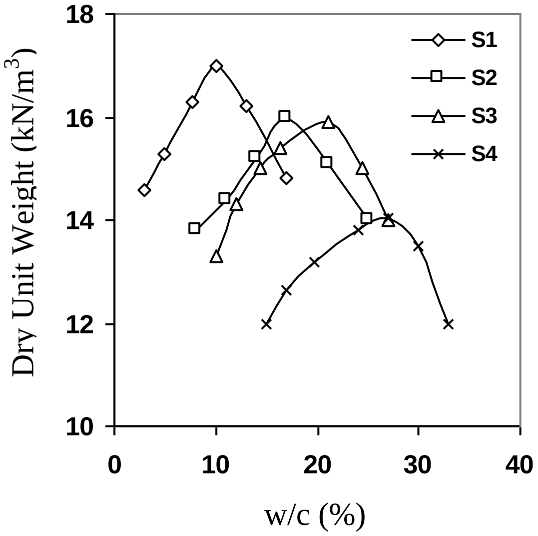

Fig. (1) Standard Compaction Curves of Soils

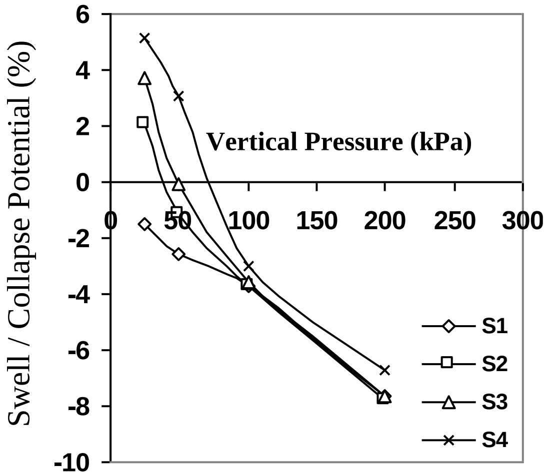

Fig. (2) Swell / Collapse Behavior of Compacted Samples

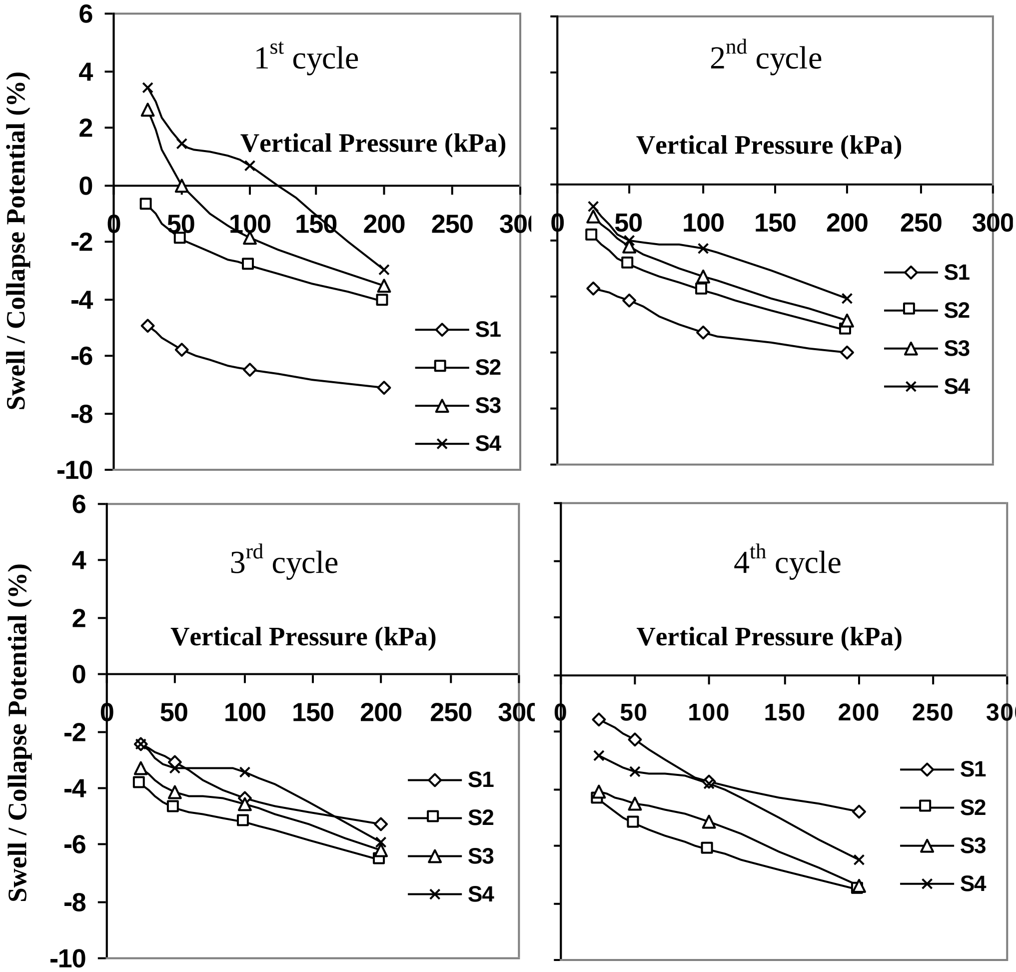

Fig. (3) Swell / Collapse Behavior of Samples During Wetting and Drying Cycles

Table (1) Physical and Chemical Properties of Natural Soils.

Properties	Values			
	Al-Gabat (S1)	Al-Salman (S2)	2nd Qadisyah (S3)	Al-Sedeeq (S4)
Liquid Limit (%)	27	40	58	84
Plastic Limit (%)	24	21	30	37
Plasticity Index (%)	3	19	28	47
Linear shrinkage (%)	-----	-----	13	20
Total Soluble salts (%)	0.5	13	4.1	3
Gypsum content (%)	-----	6	2	2
Organic matter (%)	2.9	0.9	1.2	0.87
Specific gravity	2.65	2.68	2.71	2.73
Sand (%)	63	24	13	3
Silt (%)	33	59	42	46
Clay (%)	4	35	45	51
Soil Classification (USCS)	SM	CL	CH	CH

Table (2) Values of Water Content Corresponding to (90 %) Relative Densities of Soils.

Type of Soil	w/c (%)	(90 %) Relative Density (kN/m3)
Al-Gabat (S1)	6.5	15.3
Al-Salman (S2)	11.0	14.4
2nd Qadisyah (S3)	12.0	14.31
Al-Sedeeq (S4)	17.0	12.64

Table (3) Values of Cracks Area and Number of Segment among Cracks During Drying Cycles

Loads (kPa)	Al-Gabat Soil (S1)							
	1st Drying		2nd Drying		3rd Drying		4th Drying	
	CA/ISA	NOS	CA/ISA	NOS	CA/ISA	NOS	CA/ISA	NOS
25	---	---	---	---	---	---	---	---
50	---	---	---	---	---	---	---	---
100	---	---	---	---	---	---	---	---
200	---	---	---	---	---	---	---	---
Al-Salman Soil (S2)								
25	1.0	---	2.1	---	5.3	---	7.1	2
50	1.3	---	3.0	---	6.75	1	9.35	3
100	1.93	---	4.3	1	8.4	3	10.35	6
200	2.6	---	5.15	2	10.0	4	14.63	10
2nd Qadisyah Soil (S3)								
25	1.45	---	3.6	2	6.9	5	8.7	9
50	1.8	---	4.3	4	8.2	7	11.1	13
100	2.54	2	6.3	7	10.1	12	14.6	17
7200	4.1	5	8.2	11	13.3	16	18.0	23
Al-Sedeeq Soil (S4)								
25	1.7	1	6.3	7	10.4	13	14.7	18
50	2.6	5	7.6	9	12.3	17	17.0	24
100	3.85	9	9.4	22	15.1	23	19.7	33
200	5.45	13	11.65	27	17.8	30	23.3	38

Table (4) Collapse Severity of Soils Samples

Soil Type	Percent Collapse at (100) kPa		Severity of Collapse		Severity of Collapse According to Fookes, 1990	
	Compacted State	Fourth Wetting/Drying State	Compacted State	Fourth Wetting/Drying State	Percent Collapse	Severity of Problem
S1	3.7	3.07	Moderate Trouble	Moderate Trouble	0 – 1	No Problem
S2	3.7	7.61	Moderate Trouble	Trouble	1 – 5	Moderate Trouble
S3	3.5	5.1	Moderate Trouble	Trouble	5 – 10	Trouble
S4	3.0	3.8	Moderate Trouble	Moderate Trouble	10 – 20	Sever Trouble
					20	Very Sever Trouble