EFFECT OF WETTING / DRYING CYCLES ON THE SWELLING POTENTIAL OF ANKAWA ALLUVIAL SEDIMENTS

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Abstract:
This research deals with the phenomenon of swelling in local clayey soil in Iraq, which is characterized as a sedimentation region rich in various ions that aid in the formation of clay soil. The mineral composition of the clay particles is one of the main factors that affect the soil's swelling. The soil studied is brown clay soil, classified according to the Unified Soil Classification System (USCS) as clay soil with low plasticity (CL), containing approximately 35-40% clay materials. The test results for undisturbed samples, with an initial moisture content of 14% and dry density equal to 16.5 kN/m^3, indicate that the swelling percentage starts to decrease significantly in the first cycle, reaching 6.8%. Subsequent cycles further reduce the swelling until it stabilizes in the fifth cycle at a ratio of 3.4%. This reduction in swelling is attributed to the shrinkage of the soil during drying, which affects the soil structure and arrangement of particles, transforming the soil structure into a flocculated state. This alteration occurs during the first five cycles, after which the swelling behavior stabilizes in the sixth and seventh cycles. The swelling pressure also decreases with an increase in the number of cycles, reaching stability around the fifth cycle. The most significant change in pressure occurs during the first cycle, with a decrease of 15.9% compared to the initial pressure. The pressure then gradually decreases until reaching 136 kN/m^2 in the fifth cycle, representing a reduction of approximately 30.25%. These results are significant for estimating the swelling pressure and volume change of clayey soil.
Keywords: Drying-Wetting cycle, Clayey Expansive Soil, Swelling Percentage, Expansive Clay Characteristics.

تأثير دورات الترطيب والتجفيف على الانتفاخ المحتمل لتربة عين كاوه المترسبة

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الخلاصة:

يتناول هذا البحث ظاهرة الانتفاخ في التربة الطينية في شمال العراق التي تتميز بأنها منطقة ترسيب غنية بالأيونات المختلفة التي تساعد في تكوين التربة الطينية حيث أن التركيب المعدني لحبيبات الطين هو احد العوامل الرئيسية التي تؤثر على انتفاخ التربة. التربة المدروسة هي تربة طينية بنية مصنفة حسب نظام تصنيف التربة الموحد (USCS) على أنها تربة طينية منخفضة اللدونة (CL) وتحتوي على نسبة (35-40)٪ من المواد الطينية. أشارت نتائج الاختبار للعينات غير المضطربة ذات المحتوى الرطوبي الأولي بنسبة (14)٪ وكثافة جافة تساوي (16.5)٪ كيلو نيوتن / م^3 إلى أن نسبة الانتفاخ بدأت في الانخفاض بشكل ملحوظ في الدورة الأولى للترطيب والتجفيف لتصل إلى (6.8)٪ ثم بدأت تتناقص في الدورات اللاحقة حتى استقرت في الدورة الخامسة حيث بلغت النسبة (3.4)٪. يرجع هذا التغيير إلى الضغط السلبي للتربة بسبب الجفاف الذي يؤثر على بنية التربة وينظم وضع الجزيئات. يحدث التحول خلال الدورات الخمس الأولى ثم يكون هناك القليل من التغيير حتى الاستقرار. انخفض ضغط الانتفاخ أيضًا مع زيادة عدد الدورات حتى يستقر تقريبًا في الدورة الخامسة. أكبر تغير لهذا الضغط في الدورة الأولى حيث انخفض بنسبة (15.9)٪ من الضغط الأولي ثم ينخفض تدريجياً حتى الوصول إلى الدورة

الخامسة إلى (136 كيلو نيوتن / م^2) مع انخفاض حوالي (30.25)٪. أن هذه النتائج مهمة لمعرفة ضغط الانتفاخ وتغير حجم التربة الطينية.

1. Introduction

2. Expansive soil is defined as soil that undergoes changes in its moisture content, resulting in an increase in volume (swelling) when the moisture content increases and a decrease in volume (shrinkage) when the moisture content decreases [1]. Swelling in soil is considered one of the most significant challenges encountered by civil engineers [2], particularly in regions with arid or semi-arid climates. It leads to material, time, and financial losses due to damage inflicted upon buildings, facilities, irrigation channels, and roads constructed on such soil. This behavior can be attributed to alterations in the engineering properties of expansive soil, including strength, compressibility, and permeability. Foundations built on this type of soil experience uplift forces caused by soil swelling, resulting in severe damage and potential failure. Engineers must take into account specific construction or design criteria when working on projects involving expansive soil, in order to address the potential problems associated with such soils. The extent of soil swelling is influenced by various factors, including the type of clay mineral present, its proportion in the soil, soil density, the ratio of active clay particles to non-clay particles, natural water content, and the applied stress on the soil [3-6].

In order to investigate swelling, it was crucial to elucidate the underlying mechanism of this phenomenon, with all studies on this mechanism being based on the physicochemical properties of clay soil [7]. The properties of the water-clay soil interaction system, including the ion double layer, play a fundamental role in the swelling mechanism. The presence of the ion double layer affects various engineering properties of clay soils, such as the montmorillonite mineral. The larger the size of the ionic double layer, the higher the susceptibility of the soil to swelling [8].

3. Methods and Material

The samples were collected from Ankawa a suburb of Erbil in the Kurdistan north of Iraq. Figure 1 presents the geological map of Iraq [9] and the area of the study which is covered by alluvial sediments as shown in the map.

2.1. Sampling

A test pit was excavated with appropriate dimensions of 3 * 3 meters and a depth of up to 2 meters in order to obtain undisturbed soil samples. The iron cylinder used for sampling has a diameter of 76 mm and a height of 19.05 mm. This ring is inserted into the soil by applying pressure using upper rings connected to the solidifying ring from the top. Excess soil is carefully removed from the bottom, top, and sides of the ring. The samples are then tightly wrapped and sealed using various tools. Layers of aluminum foil and plastic bags are placed to maintain the moisture content of the samples. Subsequently, the samples are transported to the laboratory for the necessary tests to be conducted.

2.2 Laboratory Tests

2.2.1 Grain-size Analysis

The grain size analysis test was performed using sieve analysis for the coarse sandy portion, and a hydrometer was utilized to determine the clay content percentage in accordance with the standard procedures. [10].

2.2.2 Atterberg limit

Using the Atterberg test to find the liquid limit (L.L) and plastic limit (P.L) according to [11]. Through this, it was found that the soil classification is low plasticity (CL) lean clay, according to the Unified Classification System (UCS).

2.2.3 Specific Gravity (G_s)

The experiment was carried out in a laboratory according to ASTM [12] to find the specific gravity.

2.2.4 Clay Activity Index

The activity index is an indicator to characterize the clay stability concerning the water content. By knowing the percentage of clay materials and the plasticity index (P.I), the amount of clay activity index defined by Skempton [13], as:

$$\text{Activity} = (P.I)/(clay\%) \qquad (1)$$

Where:

P.I = L.L – P.L (2)

Where L.L is the liquid limit and P.L is the plastic limit.

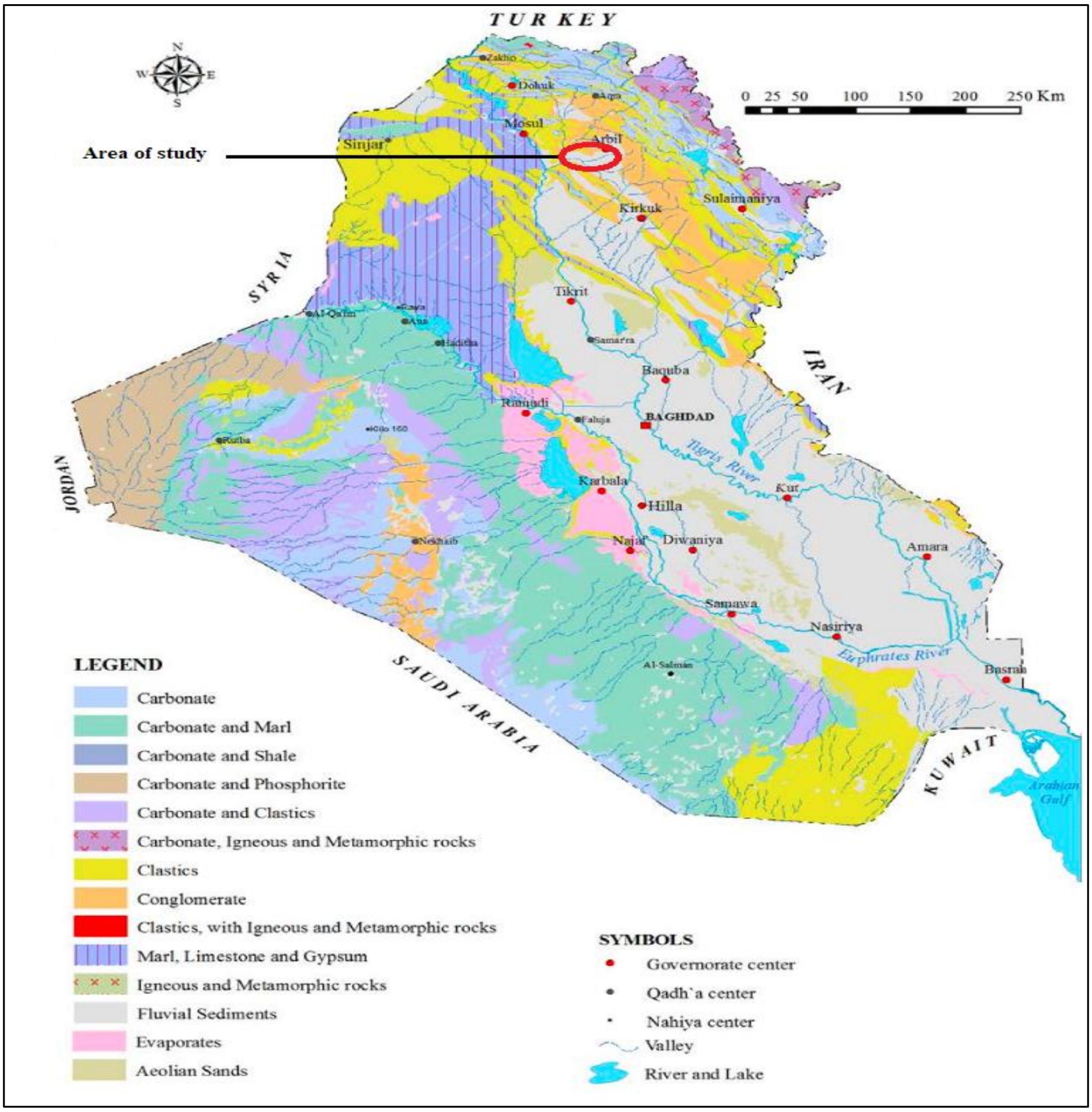

Figure 1: Geological map of Iraq and the area of study (after Sissakian and Saeed [14]).

2.2.5 Dry Density

The maximum density was determined through the standard Proctor test and the modified Proctor test. The optimum moisture content (O.M.C) is determined based on the dry density and water content curve.

2.2.6 Compression

The Odometer test is utilized for soil compressibility and swelling characteristics specimen is then left to naturally dry for approximately 110-120 hours until it reaches a according to ASTM [15]. The test is conducted under two soil conditions: dry and wet. Initially, the compression test is performed on the soil specimen at its natural moisture content. Subsequently, the soil specimen is immersed in water for 24 hours at a temperature of 25°C, allowing for the determination of the magnitude and percentage of swelling resulting from wetting. The soil moisture content close to its field moisture. This process is repeated, subjecting the soil to cycles of wetting, testing, and drying in order to assess the impact of these cycles on the swelling characteristics. Please refer to Table 1 for further details [see Table 1]. These cycles of wetting, testing, and drying are repeated to characterize the impact of wetting and drying cycles on the swelling characteristics.

3 .1 Results and Discussion

3.2 Physical Properties

3.3 The physical properties of the soil samples collected from the field are provided in Table 1. The results of the sieve analysis and hydrometer test indicate that the sample primarily consists of fine particles, specifically clay and silt. Based on the liquid limit (L.L) and plasticity index (PI) calculated using equation (2), the soil is classified as low plasticity clayey (CL) soil, as shown in Figure 2. The activity index, determined using equation (1), suggests that the soil exhibits normal activity clay characteristics, as defined by Özdemir and Gülser [16]. This outcome suggests that the clayey soil used in this study may not experience significant swelling during the wetting and drying stages.

3.2 Swelling Characteristic

Figure 3 illustrates the relationship between the swelling rate and the number of wetting and drying cycles. The findings indicate that the highest swelling rate of 6.8% was observed during the initial cycle. Subsequently, the swelling rate gradually decreased and reached stability at the fifth cycle, with a percentage of 3.40%. This decrease in swelling can be attributed to the soil's shrinkage during drying, which impacts the soil structure. The shrinkage leads to irreversible plastic deformation caused by pore collapse, as well as recoverable deformation resulting from water wetting the soil aggregates [17] [18]. Particularly, the ability of inter-water/prose space to attract the water into inter-aggregate, intra-aggregate, and inter-lamellar spaces as stated by [19, 20].

As a result, the swelling potential decreases in the subsequent cycles until equilibrium is reached [21]. The findings indicate that elastic equilibrium can be achieved after several cycles. This can be attributed to the redistribution of the clay structure [22, 23]. The dotted red line in the figure represents the polynomial correlation between the swelling percentage (S%) and the number of cycles (n).

Table 1: The physical and index properties of clayey soil

Grain-size Analysis		**Atterberg limit**		**Activity = (P.I)/(clay%)**	**Specific Gravity (G_s)**	**Dry Density**	
Clay	38%	L.L	48%			Standard Compaction	$\gamma_{d\ max.}$ = 16.5 KN/m^3 O.M.C %= 18%
Silt	56%	P.L	18%	0.79	2.7	Modified Compaction	$\gamma_{d\ max.}$ = 17.6 KN/m^3 O.M.C.% = 16%
Sand	6%	S.L	10%			Field Density	γ_{field} = 14.5 KN/m^3 w.c = 14%

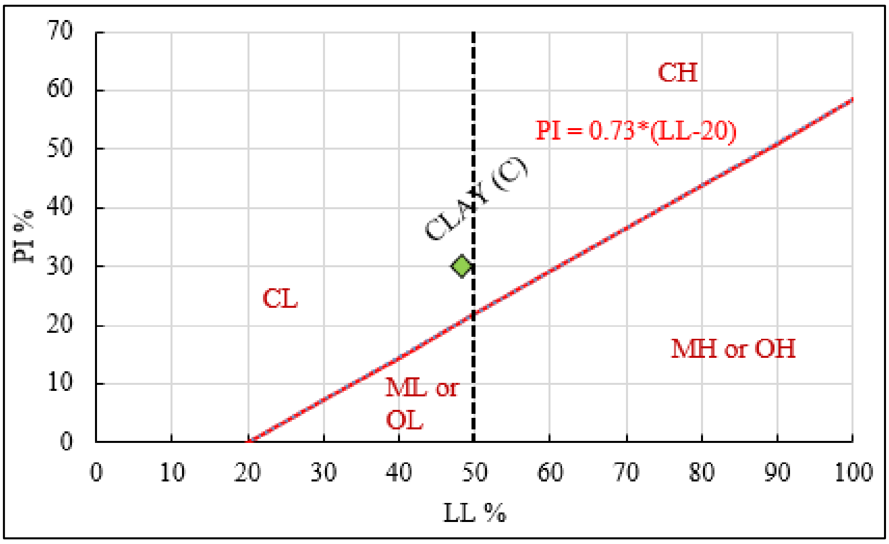

Figure 2: Group symbol of soil using the A-Line method.

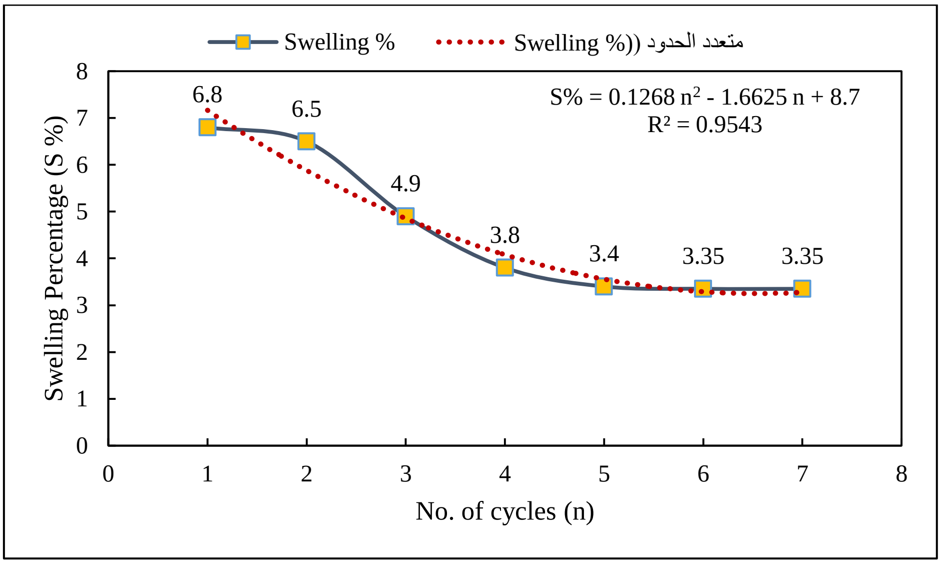

Figure 3: The swelling percentage concerning the number of drying and wetting cycles.

The value of the coefficient of determination (R^2) indicates a well-fitting between the graph parameters. This correlation is represented by the equation below:

$$S\% = 0.1268\, n^2 - 1.6625\, n + 8.7 \qquad (3)$$

Similarly, Figure 4 depicts the relationship between swelling pressure and the number of wetting and drying cycles. It is evident that the swelling pressure decreases as the number of cycles increases, eventually reaching a state of near-stabilization around the fifth cycle. Notably, the most significant change in swelling pressure occurred between the second and third cycles, with a reduction of 15.9% compared to the value observed in the second cycle. The initial swelling pressure was 195 kN/m^2, gradually decreasing to 136 kN/m^2 by the fifth cycle, resulting in a decrease of approximately 30.25% compared to the initial pressure value.

The change in swelling pressure observed during the wetting and drying cycles can be attributed to the rearrangement of soil particles [24-26], resulting in a decrease in swelling pressure [27]. These findings are consistent with previous studies conducted by Wen, Chen

[17], and An, Kong [28]. This behavior can be justified by the fluctuation of soil particles during the wetting process, which leads to a loss of connectivity between pores and an increase in the number of isolated pores. The trendline between the values of swelling pressure (Sp) and the cycles of wetting (n) indicates a power correlation, as shown below:

$$Sp = 190.48 \; n^{-0.189} \quad (4)$$

5. Conclusions

An experimental study was conducted to investigate the impact of wetting and

- The analysis of sieve and hydrometer tests indicated that the clay and silt content accounted for the majority of the fine content in the clayey samples.
- The percentage of swelling and the swelling pressure exhibited decreasing pattern with the cycling of wetting and drying, highlighting the significant effect of these cycles on clayey soil swelling. This

drying cycles on the swelling pressure and percentage of swelling of low plasticity clayey soil. The results revealed a decreasing trend in the swelling pressure as the number of wetting and drying cycles increased.

- Based on the activity index value, the clayey soil in this study was classified as normal active clay. This indicates that the interaction between the clay soil and water in terms of swelling was considered normal.

behavior was characterized by a nonlinear correlation between the swelling percentage or pressure and the number of wetting and drying cycles. However, it should be noted that this empirical correlation is specific to the soil type, including its physical and compositional characteristics, as well as the experimental design used in this study.

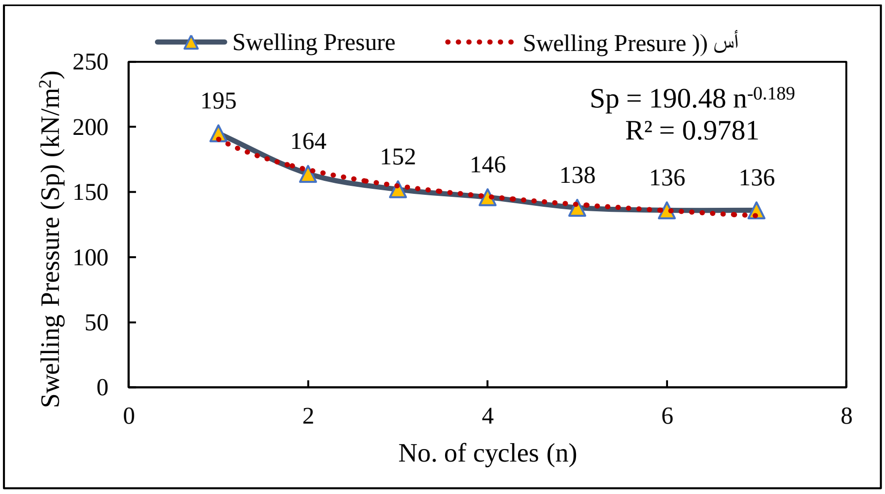

Figure 4: The swelling pressure to the number of drying and wetting cycles.

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