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Effect of Wetting and Drying Cycles on Expansive Soils Using Cement Kiln Dust

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Abstract

In this study, the effect of cyclic wetting and drying (W/D) on the swelling behavior of chemically stabilized expansive soil of full swell-partial shrinkage is investigated.Cement kiln dust (CKD) is used as an additive for expansive soil stabilization.Atterberg limits and linear shrinkage of natural and stabilized soils are performed with different percentages of CKD, ranging between 2%–20%.The standard compaction test for natural soil and that with 10%CKD is conducted. Six W/D cycles at optimum moisture content and maximum dry density are performed on five different percentages (6%, 8%, 10%, 12%, and 14%) of CKD with expansive soil to examine the effect of W/D on the swelling behavior of natural and stabilized specimens.Deformation and swelling pressure of untreated and treated soil decreased when the number of cycles increased.CKD stabilization of soil samples showed a lower deformation and swelling pressure than that of untreated soil during W/D cycles.which remained unchanged from the fourth cycle.The deformation and swelling pressure of 10% CKD stabilized specimens at high initial water content are lower than that of stabilized specimens at low initial water content.However,stabilized specimens with high dry density exhibit high deformation and swelling pressure.Results show that an initial beneficiary effect of CKD stabilization is observed under W/D cycles.The swelling of stabilized specimens decreases when the number of cycles increases, from the fourth cycle, the deformation and swelling pressure remain unchanged.However,10%CKD shows the most reduction in swelling with most economical percentage during W/D cycles and reached the equilibrium condition at the fourth cycle.

1.0 Introduction

A considerable amount of expansive natural soil is available worldwide.The word expansive soil commonly refers to soils that show substantial volume change with varying water content. High swelling potential and shrinkage, high plasticity, and low strength are important characteristics of expansive soil. These soil features often result in heave and shrinkage-related cracks in building foundations in residential buildings, highways, buried utilities, and airfield pavements (Nelson et al., 1997).

In arid and semi-arid areas of the world, moisture and rainfall amount considerably vary in different seasons, and structures, such as highways and small buildings built on expansive soils, encounter swelling and shrinkage cycles (Basma et al., 1996). Expansive soil occurs in certain areas characterized by various weathering conditions. These areas contain clay deposits and experience changing periods of rainfall and drought. Wetting and drying (W/D) processes occur due to the instability of the soil (Estabragh et al., 2013). Seasonal alternation leads to remarkable instability due to the W/D cycles in expansive soil. Cracks and deformations, which include swelling and shrinkage, could be observed in the structures, such as sanitary landfill facilities, as a result of the cycles. Soil stabilization methods, such as chemical additive stabilization, prewetting, prevention of water content increments, and pre-loading, have been commonly applied to solve swelling troubles (Akcanca et al., 2012). The expansive soil experiences swelling and shrinkage cycles during the alternate wet and dry seasons. Such cyclic motions of the ground cause substantial damage to the established structures. Therefore, the influence of the W/D cycle on the swelling behavior of expansive natural soils is validated (Rao et al., 2001).

Many researchers investigating the effect of cyclic W/D on the swelling behavior of natural clayey soils have recently emerged. Some researchers found that the potential swelling decreases when expansive clayey soils are repeatedly subjected to swelling and then subsequently allowed to dry to their initial water content (Kalkan, 2011). Research results on the influence of W/D cycles on the stability of fine-grained soils are disparate and dependent on the stabilizer percentage, soil type, curing conditions, and test methods (Aldaood et al., 2014). Determining the swell potential of expansive soils is commonly performed by one cycle of wetting. The number of W/D cycles also considerably influence the behavior of expansive soils. The influence of several cycles on the swelling and shrinking behaviors of expansive soils must be considered because continuous W/D cycles are naturally observed in soils as the outcome of environmental impact (Tawfiq et al., 2009). The changes in the swelling behavior of expansive natural soils are well documented due to the W/D cycles. However, studies that examine the effect of W/D cycles on the swelling behavior of chemically stabilized soils are insufficient. The long-term behavior of foundations and earth structures should be evaluated by employing chemically stabilized soils to perform such a study (Rao et al., 2001).

Numerous studies on the influence of chemical additives (fly ash, CKD, and lime) in expansive soil swelling are available. However, studies on the long-term performance of W/D cycles on a chemical agent are few. This study aims to investigate the effect of W/D cycles on the swelling behaviors of expansive soil treated by CKD.

1. Literature Review

The swelling percentage increases after the first cycle when the stabilized expansive soils are allowed to fully dry to the shrinkage limit or under "full shrinkage". Meanwhile, the influence of cycling on the swelling potential of expansive soils stabilized by lime has received sparse attention (Osipov et al., 1987; Dif et al., 1991). Some researchers found that the potential swelling decreases when expansive soils are continually subjected to swell and then allowed to dry to their initial water content (referred to as "partial shrinkage") (Basma et al., 1995).

In the study of Al-Homoud et al., (1995), swell-shrink cycles were investigated under the expansive characteristics of soil exposed to W/D cycles. Tests were conducted on six different soils with a different liquid, plastic, and shrinkage limits. The full swell–partial drying method was used during the experiments. The results showed that potential swelling decreases as the number of cycles increases. Moreover, the swelling percentage reached equilibrium after conducting four to five cycles. Notably, the first cycle caused the maximum reduction in swelling.

Rao et al., (2001) indicated that swelling pressures of expansive soil stabilized by lime increase with the number of wetting-drying cycles. In this study, the swelling pressures of the lime-stabilized mixture were increased with the number of W/D cycles. (Guney et al., 2007) performed cyclic W/D tests to determine the influence of lime stabilization on the swelling potential of the soil. In this study, swelling potential and pressure tests were realized on untreated and lime-treated soil specimens subjected to W/D cycles. They observed that the essential benefits of lime stabilization were wasted after the first W/D cycle, and the swelling potential increased for subsequent cycles. The soil cushion treated with lime and cement exhibited a considerable performance improvement in all the W/D cycles and also in the key parameters, such as highest swollen level, lowest shrunken level, equilibrium swollen and shrunken level, equilibrium bandwidth, extreme displacement, operating displacement, and operating middle level. The cement-stabilized soil cushion is less effective than lime-stabilized soil cushion (Sahoo et al., 2008)

Yazdandoust et al., (2010) examined the influence of W/D cycles on the swelling behavior of expansive soil stabilized by a polymer. The experiments of the swelling–partial shrinkage cycles on untreated expansive soil and polymer-stabilized soil showed a reduction in swelling potential and pressure. During the entire cyclic process, most of the reduction in the swelling behavior of all specimens were observed in the first cycle. This phenomenon resulted in lesser values of swelling potential and pressure of stabilized specimens than those of expansive natural soil. The equilibrium cycle occurred after four cycles for all specimens.

Kalkan, (2011) studied the influence of the swell-shrink cycle on stabilized natural expansive clay samples by using silica fumes. During the experiments, full swell–partial shrink procedures were applied at the end of the experiments. An improvement in the durability of treated samples against the W/D cycle was observed. Moreover, the results of the experiments showed that swell potentials of samples rapidly reached equilibrium as the stabilizer percentage increased.

The swelling pressure values were observed at the end of each W/D cycle of oven-dried specimens a temperature of 35 ± 5 °C for approximately 24 h. The swelling pressure values of the untreated samples tend to decrease at the end of each cycle. In compliance with literature, lime-stabilized samples tend to demonstrate increased swelling pressure values during the W/D cycles. In other words, when the lime-treated samples are subjected to W/D cycles, the beneficial effect of lime stabilization in controlling the swelling pressure is partially lost. However, increasing the swelling pressure of sand–bentonite mixture solely stabilized by lime could not help reach its swelling pressure. In other words, the swelling pressure values of the unstabilized specimens at the end of the W/D cycles are more than those of the specimens stabilized by lime (Akcanca et al., 2012). When the axial swell after each cycle is considered, the swell percentages are reduced at the first cycle and remain nearly unchanged or slightly increase or decrease in the consecutive cycles for all samples. The addition of fly ash provides a maximum advantage, and nearly the same swell percentages are obtained for 15% and 20% fly ash-treated samples (AS, 2012).

Estabragh et al., (2013) performed W/D cyclic experiments on expansive natural soil. Treated soil showed that the potential swelling of untreated soil decreased when the W/D cycles increased. Cement- and lime-stabilized soils also decreased the swelling potential. The total axial deformation due to the addition of cement is more than that of lime, but the coal ash-stabilized soil was negatively influenced by the W/D cycles. The influence of successive W/D cycles on the hydro-mechanical characteristics of lime-treated clayey soil was evaluated. Osmotic suction-controlled oedometers were used to define the swelling–shrinkage behavior of soil under successive W/D cycles of small capacities. The efficiency of the treatment on volumetric behavior remained unchanged while substantial degradation of the yield stress was observed, thereby indicating the stabilization process. This study observed that the evaluation of the mechanical sustainability of a lime-treated material subjected to W/D cycles demands experiments in factual conditions (Cuisinier et al., 2014).

From the aforementioned studies, W/D due to seasonal moisture change leads to poor stabilization performance, thereby causing failures to the established structures. However, limited information is available to understand the technique causing these failures, and most of the research studies did not examine the effects of W/D on the swelling properties of stabilized expansive soil via CKD. Therefore, understanding the role of the W/D cycles on the durability of chemical stabilization is essential. For this purpose, one expansive soil with high index properties is selected for this study and stabilized by CKD subjected to W/D cycles. Table 1 shows a summary of the researchers that worked on the W/D cycle on natural and stabilized expansive soils.

Table 1. Wetting/Drying technique applied to stabilized expansive soils in previous studies by different researchers

Researchers	Type of stabilizer	No. of Cycles	Drying Temperature
Osipov et al. (1987)	Nil	Six cycles	(20 °C–25 °C)
Basma et al.(1995)	Nil	Six cycles	Room temperature 24 °C
Al-Homoud et al. (1995)	Nil	Five cycles	Air-dry temperature
Rao et al. (2001)	Lime	Four cycles	40 °C
Guney et al. (2007)	Lime	Six cycles	Room temperature 24 °C
Sahoo et al. (2008)	Lime and Cement	Five cycles	40 ± 5 °C
Yazdandoust et al. (2010)	Polymer	Six cycles	40 ± 1 °C
Researchers	**Type of stabilizer**	**No. of Cycles**	**Drying Temperature**
Kalkan (2011)	Silica Fume	Five cycles	Room temperature 22 °C
Akcanca et al. (2012)	Lime	Five cycles	35 ± 5 °C
AS (2012)	Lime and Fly ash	Five cycles	45 ± 5 °C
Estabragh et al. (2013)	Nil	Six cycles	Constant room temperature
Cuisinier et al. (2014)	Lime	Five cycles	60 °C

. Materials

3.1 Soil

Field trips were conducted before commencing this study to find the soil with highly plasticity index. The physical and geotechnical property of the soil is realized according to the American and British standards, and the details of the test results are presented in Table 2.

Table 2. Results of physical and geotechnical properties of the soil

Description	Method	Results
Liquid Limit (%)	ASTM D 4318-14	61.01
Plastic Limit (%)	ASTM D 4318-14	33.48
Plasticity Index (%)	ASTM D 4318-14	27.53
Linear Shrinkage (%)	ASTM C 356-10	15.40
Specific Gravity (Gs)	ASTM D 854-14	2.74
% of Clay Fraction ≤ 0.002 mm	ASTM D422-2007	53.5
Maximum Dry Density kN/cm^3	ASTM D698-12	15.7
Optimum Moisture Content %		23
Swell %	ASTM D 4546-08	7.88

The X-ray diffraction analysis was also conducted on the soil to identify the clay chemical composition. This test was performed by Slemani construction laboratory. The chemical analysis results of the soils are presented in Table 3.

Table 3. Soil chemical properties

Description	Results, %
$CaCO_3$	43.5%
Cl	0.006%
SO_3	0.022%

3.2 Cement Kiln Dust (CKD)

Cement kiln dust (CKD) is a waste by-product of manufactured Portland cement. CKD is a fine powder material, portions of which occasionally contain reactive calcium oxide depending on the location within the dust collection system, the type of operation, the dust collection facility, and the type of fuel used. The X-ray diffraction analysis was conducted on the CKD to identify the chemical composition. This test was performed by the Slemani construction laboratory. The results of the chemical analysis of the CKD are presented in Table 4.

Table 4.Chemical properties of CKD

Description	CKD
MgO	1.78%
Al_2O_3	3.64%
SiO_2	20.03%
SO_3	1.93%
CaO	58.64%
Fe_2O_3	2.77%

4. Results and Discussions

4.1 Effect of Additives on Liquid Limit

In this study, the liquid limit decreases when the stabilizer percentage of CKD to the expansive soil increases. Figure 1 shows that the optimum reduction percentage is 10% of CKD.

4.2 Effect of CKD on Plastic Limit and Plasticity Index

In this study, the plastic limit decreased when the stabilizer percentage of CKD to the expansive soil increased. Figure 2 shows that the plastic limit of the soil decreased when the stabilizer percentage increased. As shown in Figure 3, the plasticity index also decreased with the addition of the CKD stabilizer.

4.3 Effect of CKD on Linear Shrinkage

Linear shrinkage of soil samples decreased when the stabilizer percentage increased. Figure 4 shows the linear shrinkage results with different CKD percentages. The figure clearly demonstrates that the optimum reduction percentage is 10% of CKD.

4.4 Effect of CKD on Compaction Characteristics

The purpose of the compaction test is to determine the maximum dry density and optimum moisture content of the soils. A compaction test was conducted for untreated and treated expansive soil by adding 10% CKD. The curves of the compaction test are shown in Figure 5. The compaction curves indicate that the optimum water content for the treated soil is reduced to 20.4%, and the maximum dry density increased to 16.7 kN/m^3.

4.5 Effect of Curing Time on Swelling Properties

For the soil sample mixed with 10% CKD as an optimum percentage, the swelling tests are conducted for the samples cured for 3, 7, 14, 21, and 28 days. The swelling percent test was conducted under the initial surcharge pressure of (1 kPa). The results of swelling percent and swelling pressure are shown in Figures 6 and 7 to demonstrate the effect of curing time. The values of the swelling percent and pressure were decreased with the increasing curing time but the values of swelling for each curing time not more different from each other. However, the amount of reduction was low after seven days of curing time. Depending on the obtained results, seven days curing is selected in this study.

4.6 Effect of W/D Cycles on Swelling Percent

Six W/D cycle tests were conducted on untreated and treated samples with 6%, 8%, 10%, 12%, and 14% of CKD at optimum moisture content and maximum dry density. These tests were performed under the surcharge pressure of 1 kPa and at a fixed drying temperature of 45 ± 1 ºC inside the oven for 24 h. The full swelling–partial shrinkage results of the W/D cycle tests are presented in Figure 8. The peak of the deformation caused by swelling generally occurred in the second cycle because of the change in water content. Then, the deformation decreased when the number of cycles increased until it reached equilibrium in the fourth cycle. Equilibrium is defined as the condition where the W/D cycle achieved constant magnitude for each cycle. For all treated samples, the deformation is generally increased at the second cycle due to a change in water content, and the equilibrium condition is reached at the fourth cycle.

The deformation caused by the swelling of treated soil with CKD is compared with that of untreated soil, which decreased when the number of cycles increased. A second cycle showed a peak deformation because of the change in water content. By comparing the results of the swelling percent with different CKD percentages as a stabilizer for expansive soil, the soil treated with 10% CKD can be considered the best economical stabilizer percentage compared with that of other CKD percentages. However, 14% CKD as a stabilizer showed the most reduction in deformation but not as economical as that of 10% CKD.

4.6.1. **Effect of Variation of the Moisture Content on the Swelling Percent during W/D Cycles**

Six W/D cycle tests (full swelling–partial shrinkage) was performed on the soil samples treated by 10% CKD,and the treated soil prepared at the maximum dry density of 15.7 kN/m^3 and different initial moisture contents of (17.2%, 19.1%, 26.9%, and 23%). The samples are tested for measuring the swelling percent under the surcharge pressure of 1 kPa, and all results are shown in Figure 9. The result of an untreated soil sample that prepared at the maximum dry density and optimum moisture content also shown in Figure 9.

The treated soil sample with low initial moisture content evidently swells more than other samples with additional initial moisture contents. Moreover, the deformation caused by swelling of the second cycle is always more than that of the subsequent cycles. All samples attained an equilibrium state at the fourth cycle of W/D. Therefore, the deformation of the treated soil sample with high initial moisture content mostly decreases when the number of W/D cycles increases more than that of the treated soil sample prepared with low initial moisture content.The deformation of the treated soil sample with 10%CKD was less than untreated soil sample during wetting and drying cycle.

4.6.2. Effect of Dry Density Variation on the Swelling Percent during W/D Cycles

The effects of W/D cycles of the soil samples treated by 10% CKD and compacted at the optimum moisture content and different dry densities under a surcharge pressure of 1 kPa are shown in Figure 10. Also, the result of an untreated soil sample that prepared at the maximum dry density and optimum moisture content shown in Figure 10.The peak deformation of the samples is evidently observed in the second cycle. Afterward, the deformation decreases when the number of cycles increases and reaches the equilibrium condition in the fourth cycle. By comparing the results of the swelling percent of the treated soil specimens, the deformation caused by swelling for high dry density is considerably larger than that of the low dry density.The deformation of the treated soil sample with 10% CKD was less than untreated soil sample during wetting and drying cycle.

4.7 Effect of W/D Cycle on the Swelling Pressure

Swelling pressure was measured for six W/D cycle tests on untreated and treated soil samples with 6%, 8%, 10%, 12%, and 14% CKD at optimum moisture content and maximum dry density. The results of the swelling pressure of full swelling–partial shrinkage and W/D cycle tests of the tested specimens are shown in Figure 11. A constant volume method was used during testing, and a partial shrinkage of the samples was conducted by using a fixed drying temperature of 45 ± 1 ºC inside the oven. The swelling pressure values at the second cycle are generally larger than those of other subsequent cycles because of the change in water content. Afterward, the second cycle gradually decreased and reached an equilibrium condition in the fourth cycle. By comparing the results of the swelling pressure of untreated soil and soil samples treated with different CKD percentages, swelling pressure under the W/D cycle is reduced with the addition of CKD. Moreover, 10% of CKD as an additive stabilizer can be considered an optimum and economical percentage based on the results.

4.7.1. **Effect of Moisture Content Variation on the Swelling Pressure during W/D Cycles**

The effect of six W/D cycles (full swelling–partial shrinkage) on the swelling pressure of treated soil with 10% CKD is shown in Figure 12. Tested samples prepared at a maximum dry density of 15.7 kN/m^3, and different initial moisture contents of 17.2%, 19.1%, 26.9%, and 23%. The result of untreated soil sample prepared at optimum moisture content, and maximum dry density also is shown in Figure 12.The results showed that the swelling pressure during W/D cycles exhibit maximum values in the second cycle and gradually decreases until reaching an equilibrium condition in the fourth cycle. The results of the swelling pressure of the treated soil samples at different initial moisture contents under W/D cycles show that high initial moisture content has lower swelling pressure than that of the lower initial moisture content. The swelling pressure the treated soil sample was less than untreated soil sample during wetting and drying cycle.

4.7.2. Effect of Dry Density Variation on the Swelling Pressure during W/D Cycles

The effects of the W/D cycles on the swelling pressure of the soil samples treated by 10% CKD and compacted at the optimum moisture content and different dry densities are shown in Figure 13. The result of untreated soil sample prepared at optimum moisture content, and maximum dry density also is shown in Figure 13.The swelling pressure at a maximum dry density of 15.7 kN/m^3 during the W/D cycle shows maximum swelling pressure at the second cycle, which decreased until it reached an equilibrium condition at the fourth cycle. For the treated soil sample prepared at the low density of 14.52 kN/m^3 and optimum moisture content, the swelling pressure during the W/D cycle decreased when the number of W/D cycles increased and reached equilibrium condition at the fourth cycle. By comparing the results of swelling pressure at different dry densities during six W/D cycles, a considerable reduction in swelling pressure is observed for the soil sample prepared with 10% CKD at a low dry density of 14.52 kN/m^3. However, high swelling pressure was observed when the sample was prepared at a maximum dry density of 15.7 kN/m^3. The swelling pressure of the treated soil sample was less than untreated soil sample during wetting and drying cycle.

5. Conclusions

This study aims to investigate the effect of W/D cycles on the swelling behavior of expansive natural soil and stabilized expansive soil by CKD. The effect of adding different CKD percentages on Atterberg limit, linear shrinkage, and compaction was also studied. The following conclusions can be drawn from the results of
Fig 1. Variation of the liquid limit with % CKD
this experimental study:

1- Liquid limit, plastic limit, and linear shrinkage are decreased with the addition of CKD. From these results, 10% of CKD is found to be the best percentage of stabilization.
2- By adding 10% CKD to natural expansive soil, the value of maximum dry density is increased, and the optimum moisture content is decreased.
3- Swelling percent and pressure show a considerable reduction with the addition of CKD.

4- By applying the W/D cycles on untreated and treated expansive soil with CKD, the deformation of the treated and untreated soil is reduced when the number of cycles is increased. Large deformation is observed in the second cycle and the fourth cycle, reaching an equilibrium condition

5- For all samples during the W/D cycles, the equilibrium cycle occurs at fourth cycles. According to these results, the CKD used in this study can be effective in stabilizing the expansive soil in areas with wet and dry alternative seasons, which were simulated by partial shrinkage in this research.
6- During the entire cyclic processes, the values of deformation and swelling pressure of treated specimens are lower than those of untreated specimens.
7- Soil samples with low initial moisture content during the W/D cycle provide high deformation and swelling pressure.
8- Soil samples with low unit weight during the W/D cycle provide low deformation and swelling pressure.
9- Swelling pressure values are decreased with the addition of different CKD percentages. W/D cycle tests on untreated and treated expansive soil at optimum moisture content and maximum dry density show that the swelling pressure of treated soil is lower than that of the untreated soil. During the W/D cycles, the maximum swelling pressure observed at the second cycle and is reduced when the number of cycles is increased until an equilibrium condition is reached at the fourth cycle.

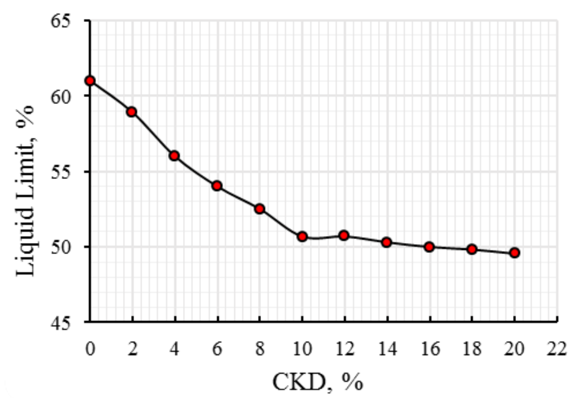

Fig 1. Variation of the liquid limit with % CKD

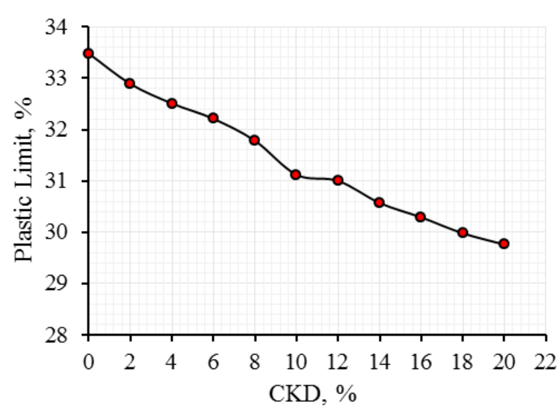

Fig 2. Variation of the plastic limit with %CKD

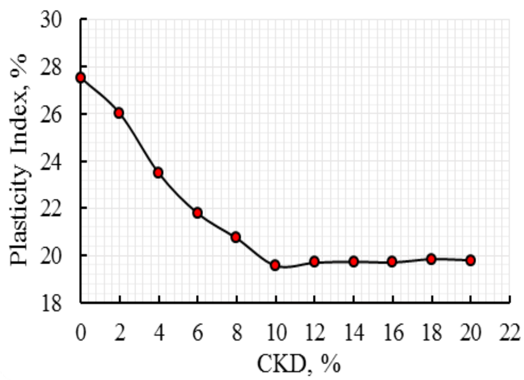

Fig 3. Variation of Plasticity Index with %CKD

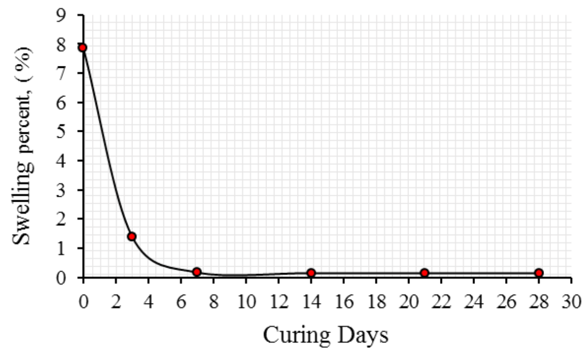

Fig 6. Variation of swelling percent with curing time of treated sample of 10 % CKD

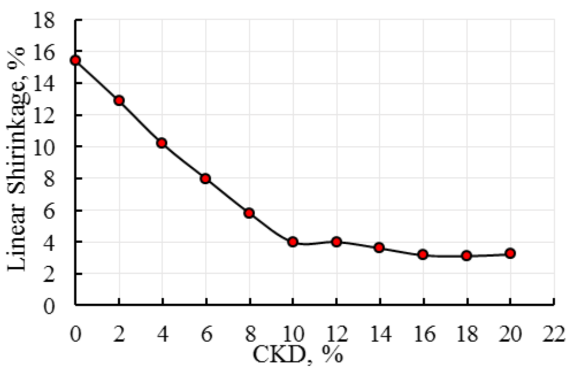

Fig 4. Variation of Linear shrinkage with %CKD

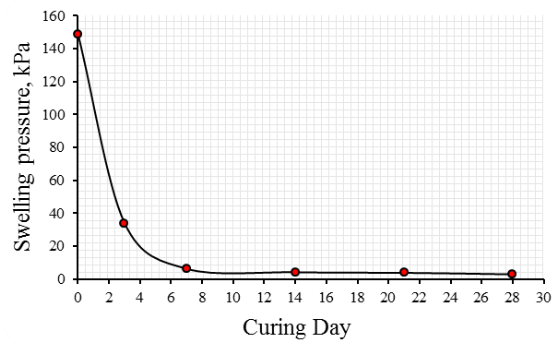

Fig 7. Variation of swelling pressure with curing time for treated sample of 10%CKD

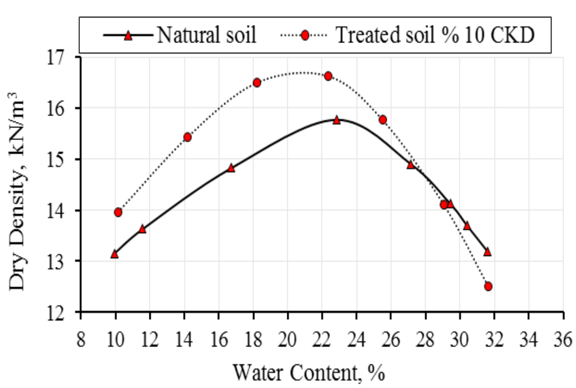

Fig 5. Variation of dry density of untreated soil and treated soil with 10% CKD and water content

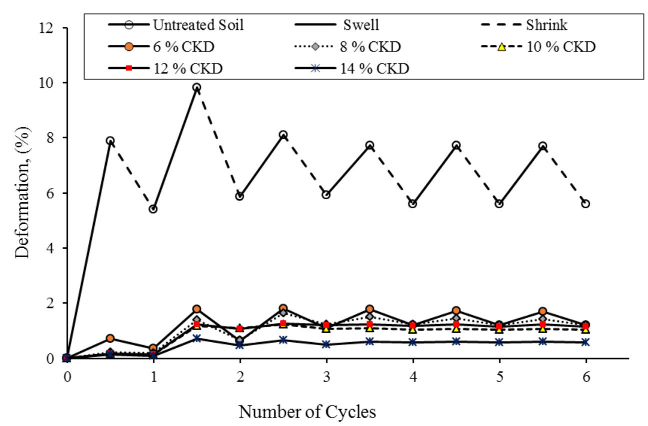

Fig 8. Variation of deformation with the number of cycles for untreated soil and soil treated with a different percent of CKD

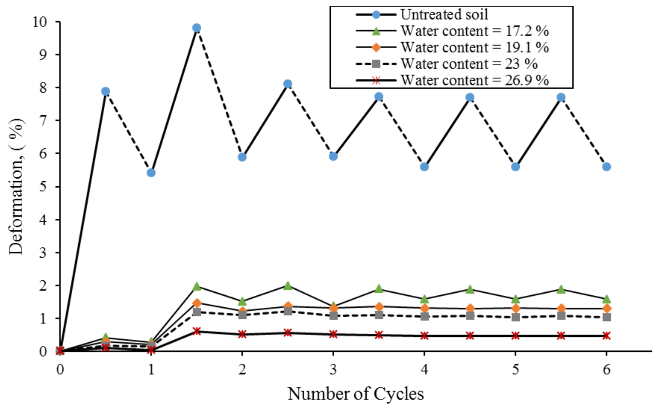

Fig 9. Variation of deformation with a number of cycles of untreated soil and treated soil with 10 % CKD at the maximum dry density and different initial moisture content

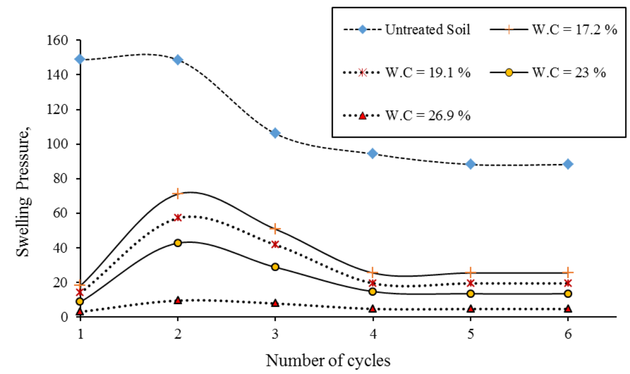

Fig 12. Swelling pressure versus cycle number for 10 % CKD at the maximum dry density and different initial moisture water content

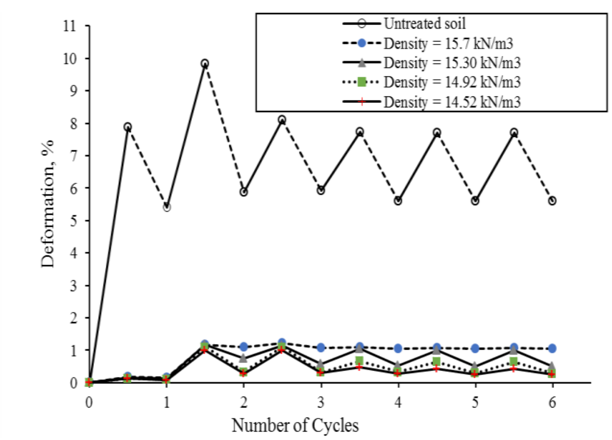

Fig 10. Variation of deformation with the number of the cycles for untreated soil and treated soil at optimum moisture content and different dry density

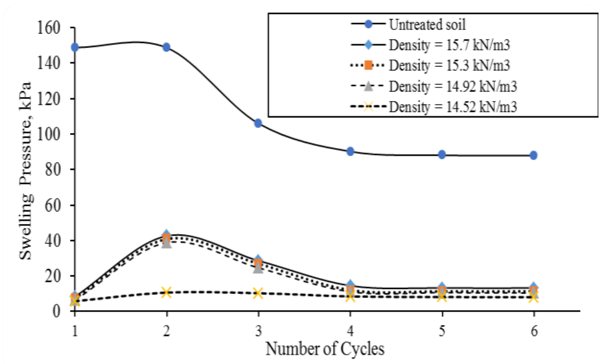

Fig13. Swelling pressure versus cycle number for untreated soil and treated soil with 10 % CKD at optimum moisture content and different dry density

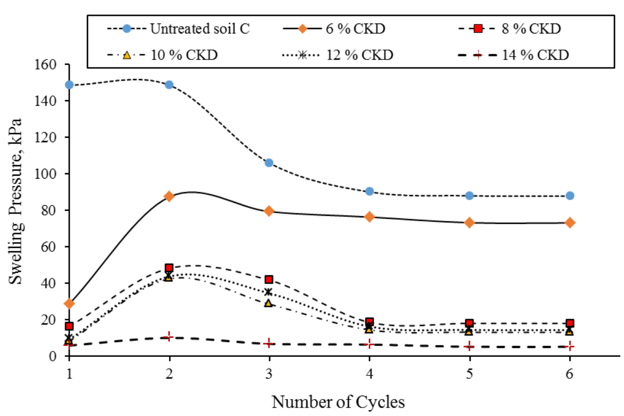

Fig11.Swelling pressure versus cycle number for different percent of CKD

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