Behavior of Collapsible Soils Improved by Fly Ash and Cement Kiln Dust

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ABSTRACT
Collapsible soils are metastable soils characterized by voids inside their building, at grain sizes ranging from silt to fine sand. On wetting, they collapse producing distortions that might cause failure of structures. In this study, addition to the natural collapsible soil, an artificial collapsible soil was prepared with the exact properties of the natural one taken from the deposit to avoid the remodel during transfer. Then, both the natural and artificial soil samples were stabilized with fly ash and cement kiln dust with several percentages. Kaolin particles were used to prepare the artificial samples with low density to represent the metastable soil structure. The fly ash and cement kiln dust were used in several percentages 5%, 10% and 15% to demonstrate the effect of using these stabilizing agents on Odometer test. The addition of fly ash (up to 15%) to the natural or artificial soil resulted in a decrease in the collapse potential (C_P) from 15.4% to 4.4 % and from 13.8% to 2.6%, respectively. The obtained results showed that treatment of collapsing soils (natural and artificial) with CKD resulted in a reduction of collapse potential from 15.4% to 0.72% and from 13.8% to 0.95%, respectively. The results showed a significant improvement of the stabilized collapsible soil over the non-stabilized one whether treated by using fly ash or CKD. Additionally, CKD showed more effectiveness than fly ash in all the undergone tests.

Keywords: Natural collapsible soil, artificial collapsible soil, Fly Ash, Cement Kiln Dust, Oedometer test.

I. INTRODUCTION

A lot of trouble in engineering happen with soils in unsaturated case in order to their voids contain both water and air. This form of material is very popular in arid or semiarid regions, where ever the water table level normally changes with weather change [1]. In fact, the collapse potential of such open structures can occasion a decrease in volume up to 30% [2]. On the other hand changes in weather could potentially cause significant changes in the soil moisture regime in many regions of the world [3]. Previous studies exhibit that collapse potential occurs in different types of soil due to the breaking of bonds of soil structure while water content raises. This bond failure in collapsible soils is classified in the following way: (i) breaking of clay bonds, which occurs in natural loose soil material (ii) removing the physical-chemical forces of clay plates, which happens in compacted collapsible soils when compacted on low dry relatively densities under certain conditions and where the largest factors influencing collapse potential are stress, initial unit weight, moisture content, type and the amount of clay [4] (iii) removing the cementation material, which occurs in soil with a cementation material as a binder. This cementation material will be fused during the moistening, causing the removal of the binding forces among the soil particles and subsequent collapse [5].

Collapse is a sudden decrease of soil volume of fill material or natural soil sediment upon immersion, without change in used stress. The inundation source may be downward infiltration of surface water, rising ground water table, the bursting of underground water supply lines or other means. Jennings and Knight suggested a procedure to evaluate the collapse potential of a soil using the double-oedometer for an undisturbed specimen at natural moisture content by placing it in an oedometer ring; then the collapse potential (C_P) is expressed in the percentage as:

$$C\,p = \frac{\Delta H}{H0} = \frac{\Delta e}{1+e0} \,.\, 100\ \% \qquad (1)$$

where; Δe = Change in void ratio in oedometer test on inundation at a given stress.
e_0 = Initial void ratio of the oedometer test specimen before inundation.
e_1 = void ratio before flooding
e_2 = void ratio after flooding [6].
They also suggested a classification of the potential severity of collapse based on the collapse potential as shown in Table 1.

II. EXPERIMENTAL WORK

II.1 Materials Used

A. Fly ash
The fly ash (class F) used in the present study. It has been bought from X- Caliber Company located at Cairo. The fly ash (class F) is light grey in color, and has a powdery texture

Table (1): Classification of the Potential Severity of Collapse

Collapse Potential, C_p (%)	Severity of collapse
0 - 1	No problem
1 - 5	Moderate Trouble
5-10	Trouble
10-20	Severe trouble
> 20	Very severe Trouble

that indicates high calcium oxide content. The chemical properties of the fly ash are show in Table 2. The chemical composition of fly ash is one of the most essential indicators of material quality for various applications. Based on the chemical properties results, the fly ash used is close to class F. Figure. 1 shows the class F fly ash used in this study.

Figure. 1. Fly ash (class F) used in the study

Table (2): Chemical Properties of Fly Ash (Class F)

Typical class F	Chemical elements (%)
SiO_2	54.9
$Al_2 O_3$	25.8
Fe_2O_3	6.9
CaO	8.7
MgO	1.8
SO_3	0.6
LOI	6

B. Cement Kiln Dust (CKD)

As shown in Table No. 3, the cement kiln dust's oxide compound is presented, where calcium oxide's compound (CaO) alone accounts for 55.06% and takes charge of exchanging ions between soil and CKD. In turn, this leads to forming more granular material and developing strength. For cement kiln dust, the Loss on Ignition accounted for 4.38%, whereas the particular gravity accounted for 2.60%. The Loss on Ignition (LOI) means losing the mass correlated to the heat of ~950°C, which is normally the contribution of noncarbonated carbon and chemically bound water. After treating soil with low Loss of Ignition (LOI %) and high free lime, promising results regarding strength were achieved.

Table (3): Oxide Composition of Cement Kiln Dust

Oxides	SiO2	Al_2O_3	Fe_2O_3	CaO	MgO
Percentage (%)	14.79	4.51	2.64	55.06	2.66
Oxides	SO_3	K_2O	Na_2O	FCaO	LOI
Percentage (%)	1.48	1.26	0.18	4.04	4.38

C. Sand

The tests were carried out on soils reconstituted in the laboratory. The sand used in the sample was screened through the 2mm sieve. Analyses and physical characteristics are summarized as follows: coefficient of uniformity CU =4.4, coefficient of curvature CC =1.1. Fig. 2, reveals various size grains. Sieve analysis was carried out for the sand to plot the grain size distribution curve. the diameters corresponding to percentage of sand passing sieves D10, D30 and D60 were determined and the uniformity coefficient $C_{u.}$ And the coefficient of curvature Cc were calculated,

Where: $C_c = \frac{D_{30}{}^2}{D_{60}*D_{10}}$ and = $Cu = \frac{D_{60}}{D_{10}}$.

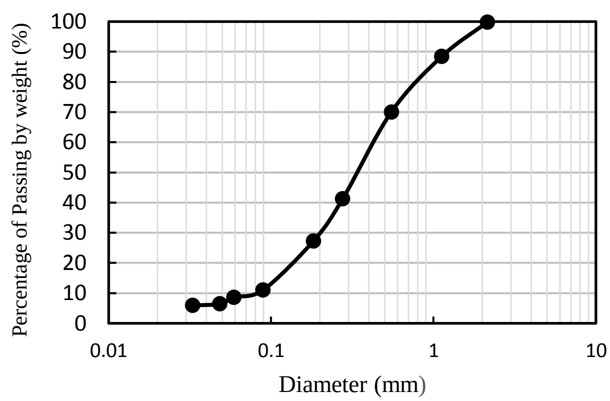

Figure 2. Particle size distributions for sand

D. Kaolin

The fine-grained soil (D < 80 mm) in this study is took out from the Bastien region, Egypt. The following physical characteristics: Liquid limit, L.L. (%) = 67, Plastic limit PL = 39, Specific Gravity, Gs = 2.7. in general, lower than 80µm, with manganese impurities, titanium and lime. Hydrometer test was carried out for the kaolin to plot the grain size distribution. Chemical Analysis is as summarized in Table 4.

To obtain the grain size distribution of the kaolin, first the soil was wet sieved and then hydrometer test was performed, grain size distribution curve of kaolin is plotted as presented in Figure 3. Hydrometer test result shows that 93.5% of the material passes a No.200 sieve and that the clay fraction is (50) percent, the silt is 43.5% as reported by the (MIT) organization.

Table (4): Chemical Analysis of kaolin

Element	Result (%)
Silicon dioxide (sio_2)	50 - 56 max
Aluminium oxide (Al_2o_3)	30 - 33 min
Iron oxide (Fe_2o_3)	1.0 - 1.3
Titanium dioxide (Tio_3)	1.3 - 1.8
Calcium oxide (Cao)	0.10 - 0.25
Magnesium oxide (MgO)	0.05 - 0.10
Sodium oxide (Na_2o)	0.07 - 0.15
Potassium oxide (k_2o)	0.03 - 0.06
Chlorine (Cl)	< 0.05
Loss on ignition (10 °c – 1000 °c)	11-12

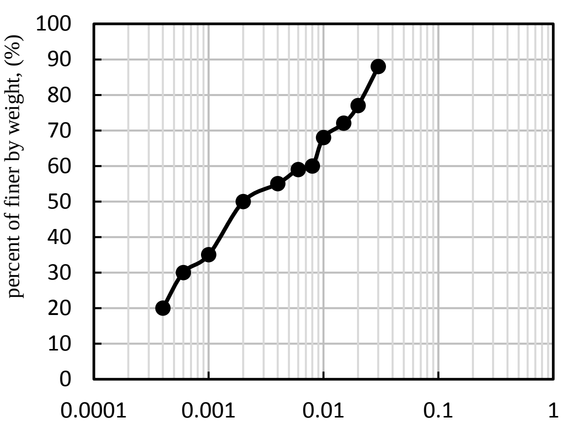

Figure 3. Particle size distributions for kaolin

E. The compaction tools

The main principle is to prepare a reconstituted soil having a certain fly ash or CKD content and a certain dry unit weight, to be compacted, then to be charged in the cell of oedometer. The apparatus of compaction of material is presented in Fig. 4a, b which is used by different investigators. It was conceived in the laboratory and described by [8&11]. It is composed of a disc having a diameter slightly smaller than the ring, fixed to guide stem mutton in the form of disc. The mutton of 136 gm. slides alongside of the rod, falls from 150 mm height and comes to strike the disc of 50.2 mm diameter to compact the materials.

III. Collapsible Soil Preparation

A. Natural Soil

The tested soil samples were obtained as disturbed samples recovered from a test pit at a site in Al-Gharbaneyat area, Borg El-Arab city, 60 km west of Alexandria, Egypt where several sinkholes have been developed. Soil samples were air dried for

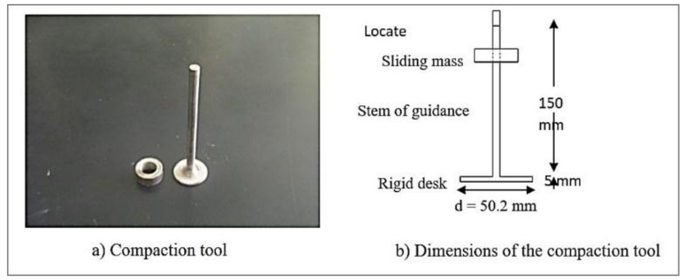

Figure 4. The compaction tool

15 days and then was divided into two parts. After this period, Hydrometer analysis was performed to obtain the grain size distribution curve of tested soil as grain sizes are too small for sieve analysis. Figure (5) shows the grain size distribution curve of tested soil. The first part samples were mixed with fly ash in amounts 5%, 10% and 15% by weight of dry soil samples gradually. Simultaneously, the second part samples were mixed with CKD in amounts 5%, 10% and 15% by weight of the dry soil samples gradually.

The properties of fly ash and CKD are presented in Table (2 and 3). In order to prepare a consolidation sample the mixture is poured in the cell of oedometer, then using the device described previously, the material is compacted in two layers with the same energy, 10 blows/layer. The tested sample is leveled inside the ring of oedometer cell taking into consideration keeping the upper surface as a plane surface. The last procedure is putting back the ring of the oedometer in the cell on which the test of compressibility described by [6]. These attempts consist to load the soil gradually, until a constant pressure of 200 kPa, then inundation by water for 24 hrs. The axial deformations of the collapsible soils were recorded by a dial gauge having a precision of 0.01mm.

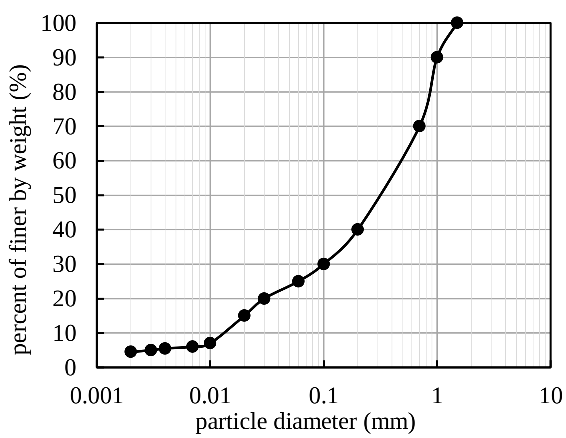

Figure 5. Particle size distributions for natural soil

B. Artificial Soil

In this study, collapsible soil mixtures were prepared in the laboratory by mixing the sand and clay and water contents. The water content and clay percentage for each soil mixture were very carefully controlled using a highly accurate sensitive balance in order to obtain the desired soil properties for each collapsible soil mixture. The soil mixtures were uniformly mixed using a concrete mixer, where the mixing procedure was carefully done over a sufficient period of time, to obtain uniform mixtures [12]. Collapse potential (C_p) is the key parameter used to define collapsible soils, and it depends mainly on initial water content, compaction effort and clay content. Therefore, in order to determine the appropriate mixture properties for soils having collapse potential 13.6 a series of response-to-wetting single oedometer tests were carried out for sand-clay mixture using kaolin clay of compaction, water and clay contents. Where oedometer test was repeated at least three times to ensure reliability.

The compaction of soil sample in oedometer ring before carrying out oedometer test, where soil was submerged at 200 kPa inundation stress [13], [14]. In this investigation, the collapsible soil was prepared in the laboratory by mixing fine sand with Kaolin clay commercially known as “rogers clay”, using a concrete mixer, then a compaction effort was applied on the soil mixture to reach the desired unit weight. The kaolin clay acts as the cementing material that bonds sand particles together at low water content (5%). The chemical analysis and physical properties of the clay is shown in Table 4 while the particle size distribution for sand and clay obtained from sieve analysis and hydrometer test are shown in Fig. 2 and 3 respectively. While Fig. 6, shows the grain size distribution curve of artificial soil

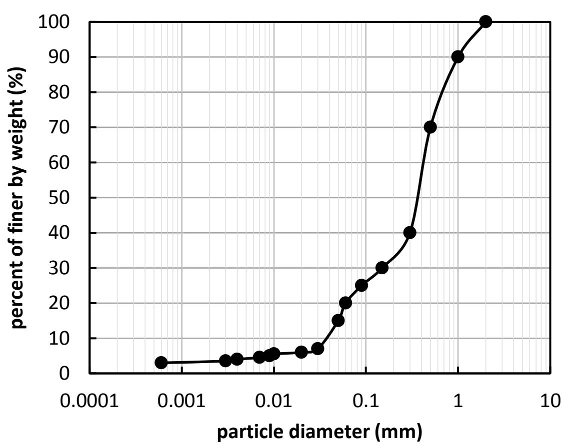

Figure 6. Particle size distributions for artificial

IV. RESULT AND DISCUSSION

It is clear from Figure (7) that the natural soil collapse potential (C_p %) decrease with the increase of fly ash content. The highest value of natural soil collapse potential occurred at 0% fly ash without any stabilization content and reached to 15.4%. While the minimum value of the natural soil collapse potential occurred at 15% fly ash to reach a value of 4.4%. It is clear from fig.8 that the artificial soil collapse potential C_p decrease with the increase of fly ash content. The highest value of artificial soil collapse potential occurred at 0% fly ash content and reached to 13.8%. While the minimum value of the artificial soil collapse potential occurred at 15% fly ash and reach 2.6%. The influences of the chemical reaction of fly ash at both macro and micro levels are explained in the following points:

1. **Soil’s Macro-Physical Behavior**: in case of mixing soil with fly ash while water is existent, there will happen a number of reactions leading to separating lime (CaO) in the binders and forming cementations and pozzolanic gels (i.e. the gel of Calcium Silicate Hydrate (CSH) and the gel of Calcium Aluminate Silicate Hydrate (CASH)). Referred to as compositions and/or pozzolanic reactions, such reactions lead to forming the gels of cementations. A rough correlation was found between the kind and amount of possible products of reaction (that’s to say the CSH for short-run strength and the pozzolanic product of reaction, and CASH for the strength gain in the long-run) and decreasing the value of collapse and increasing strength [15].

2. **Micro-Chemical Behavior**: the impact of fly ash is dependent on the theory of double layers stating that the force of interaction among layers in clay plates is dependent on the concentration of ions at the mid-plane between two adjacent parallel plates, which is called “the force of attraction” [16]. In accordance with the chemical analysis (SAR> 8), the treatment of untreated soil has abundance of bentonite by Na-type [17]. Clay plates’ surface has a high charge of Na ion one valence. In addition, an increase in double layers’ thickness and in the force of attraction between clay plates is caused by caused by the existence of cationic ions in pore water. In case of the reaction of dry bentonite with water, the Na ion one valence is hydrated in clay plates’ surfaces, resulting in increasing the distance of inter layer separation [18]. In case of treating water with 15% fly ash, calcium ions are released by fly ash, leading to the replacement of the original cations (mostly sodium ions) in clay particles. Such process is so-called “the process of cation exchange in which the lower ion valency (Na^{+1}) is replaced by the free sodium having higher valency cations (Ca^{+2}) of fly ash.

In addition, every cation tends to replace one to the left of which, resulting in a decrease in the quantity of (Na^{+1}) ions in the surface of bentonite and in the volume of the diffused double layer that surrounds the particles of clay. The particles of clay are allowed to come closer to one another due to the reduction in the diffused double layer. Further, in case of adding fly ash to soil, the reactions will happen quite quickly and the occurrence of cation replacement is dependent on whether different kinds of cations are available.

Drawing on the findings, the C_p is observed to have a slight decrease when the mixture of soil reaches 15% of fly ash, which indicates that the pozzolanic reaction starts with a great intensity in case of higher ratio of clay content/fly ash in soil with high silica and/or alumina. Then, it becomes slow in case of the very low ratio of clay content /fly ash in soil with the increase in the content of fly ash.

In loose material, the possibility of undisturbed natural soils' collapse is reliant on the soil skeleton's hydro-mechanical behavior. Such kind of collapse is caused by breaking the bonds of clay during wetting, resulting in re-arranging particles and then a total collapse. Encouraging the strong root development, the open structure is the reason why soil is subjected to collapse after load and/or water is applied. As a matter of fact, the collapse of these open structures results in up to 30% decrease in volume. Due to the different systems of bridging and bonding among the particles of the major structural silt or owing to breaking or reducing the capillary suction in soils, large voids are maintained in these soils. The cause of the collapse is the fine particles' internal erosion through soil structures. In the current study, the probable cause of collapse is the distribution of a mixture of new arrangements of dissolution of void ratio Clay Bridge and the changes in chemical.

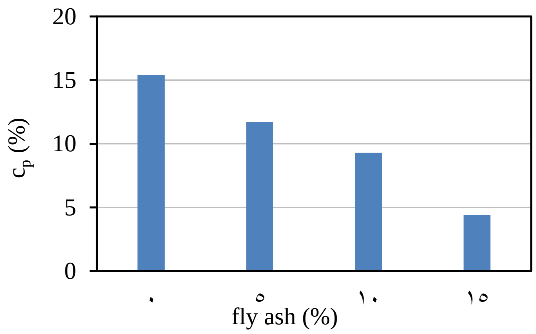

Figure 7. Relation between collapse potential of natural soil and fly ash content

From the results, it can be observed that the C_p decreases slightly when the soil mixed until reaching 15% of fly ash. This may refer to the pozzolanic reaction begins with great intensity when the (clay content/fly ash) in soil is high (with high silica and/or alumina) and then slows down when the (clay content /fly ash) ratio in soil is very low (with increasing fly ash content).

The collapse potential of undisturbed natural soils in loose material depends on the hydro-mechanical behavior of the soil skeleton. This type of collapse is due to the breaking of clay bonds during wetting, causing a re-arrangement of the particles as well as a total collapse. The open structure that encourages strong root development makes the soil susceptible to collapse upon the application of load and/or water. In fact, the collapse of such open structures can cause a reduction in volume of up to 30%.

The large voids in these soils are maintained as a result of various bridging and bonding systems between the main structural silt particles or due to the breaking or reduction of capillary suction in soils. The collapse is caused by the internal erosion of fine particles through the soil structures. In this study, the collapse probably happened due to a mix of new arrangement distribution of void ratio clay bridge dissolution and changes in chemical bonding.

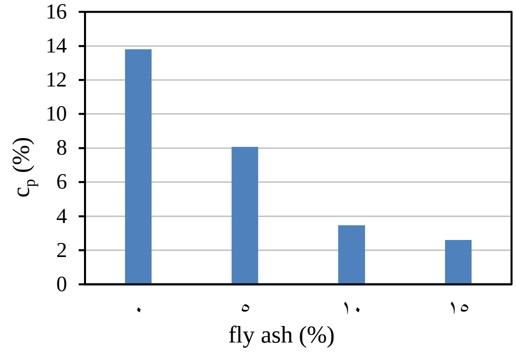

Figure 8. Relation between collapse potential of artifitial soil and fly ash content

It is clear that CKD has a better effect on potential severity of collapse from fly ash for 5%, 10% and 15% CKD content, collapse potential is reduced by 73.3%, 88.9% and 95.32% respectively for Artificial sample and 50%, 78.1% and 93.1% for natural sample and changed from "Trouble" to "no problem" as compared to untreated sample.

The optimum content for CKD is 15% as for CKD content exceeds that value, no applicability forckd-soil interaction as the CKD ratio became more than soil content plus severity of collapse reaches "no problem" state for 5%, 10% and 15% CKD content, collapse potential is reduced by 56.2%, and 61.6% respectively as compared to untreated artificial sample which can be concluded as the degree of severity of collapse is changed from "Trouble" to "moderate trouble" for both content. For 5%, 10% and 15% CKD content, collapse potential is reduced by 73.3%, 88.9% and 95.32% respectively as compared to untreated sample which can be concluded as the degree of severity of collapse is changed from "Trouble" to "moderate trouble" to no problem for both samples of soil. he optimum content for CKD is 15% as for CKD contents exceeds that value, no applicability for CKD-soils interaction as the CKD ratio became more than soil content.

For pure soil, the collapse test shows that the collapse potential is reached to 13.8%, 15.4 as shown in Fig. 10 for natural soil mix with CKD, the results of Oedometer test for (N.C.S) for different percentage of CKD. The highest collapse potential corresponds to 0% of CKD, while the lowest Collapse potential refers to 15% of CKD, while for the mix of artificial soil with CKD, as shown in fig. 11 it reduced from 6.9% at 5% CKD to 0.95% at 15% CKD. Collapse potential is significantly reduced for both natural and artificial soil with increasing of CKD content especially with high initial unit weight up to 10% CKD, and then slightly increased. This result accorded well with that obtained by [19] who studied the effect of adding different percentages of cement kiln dust (CKD) on the engineering properties of collapsible soil in central region of Saudi Arabia.

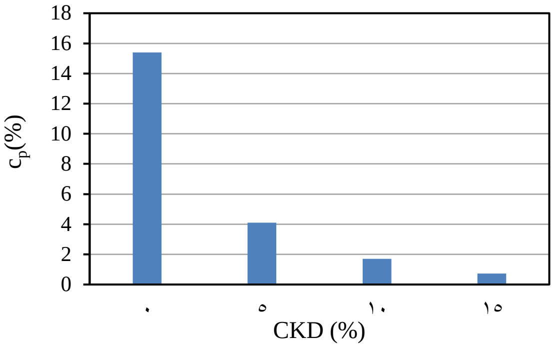

Figure 9. Relation between collapse potential of natural soil and cement kiln dust content

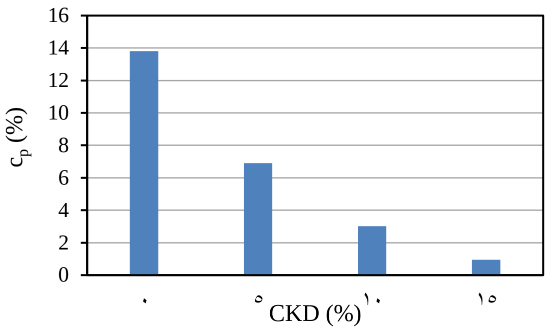

Figure. 10 Relation between collapse potential of artificial soil and cement kiln dust content

CONCLUSION

1. The collapsible artificial soil used in this study was a mixture of sand, kaolin and 5 % water.
2. After performing various experiments on soil, fly ash, CKD and soil mixed with varying proportion of fly ash and CKD, it has been observed that fly ash and CKD is improving the collapsible soil.
3. Based upon results of this study various conclusions are summarized as: Collapse potential of soil decrease with increasing fly ash and CKD content and maximum decrement occurs at 15% fly ash and 15% CKD mixing.
4. CKD has a great effect on decreasing collapse potential of artificial soil than fly ash, the reduction reached to 0.95% and 2.6% with using 15% CKD and fly ash respectively.
5. CKD also decreasing the collapse potential of natural soil more than fly ash, the reduction reached to 0.72% with using 15% CKD content, while with using 15% fly ash the collapse potential was 4.4%.

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