Journal of Engineering Sciences, Assiut University, Vol. 39, No 6, pp.1301-1319, November 2011

EXPERIMENTAL STUDING ON THE STABILITY OF SANDY SLOPES STABILIZED WITH CEMENT KILN DUST UNDER THE EFFECT OF STRIP FOOTINGS

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(Received August 22, 2011 Accepted September 5, 2011)

In this paper, presents of experimental tests carried out on physical and chemical properties of cement kiln dust. Cement kiln dust is considered a one of waste which produced in a local cement production plant production plant Portland cement manufacturing in Assuit Cement Company-Egypt. The main aim of this study is to examine some factors that influence the performance of a strip footing resting on a sandy slope by the utilization with CKD. This study aims also at establishing relationships between the bearing capacity and the CKD percentage and forming a database for future development of a rational design method. The angle of the slope was taken equal to (42o). Laboratory tests on small scale model were carried out. The experimental model was simulated by the finite element method (FEM) using the computer program PLAXIS. The verification of the numerical results by the corresponding experimental results has been done to emphasis the accuracy of the parameters used in the numerical analysis.

1. INTRODUCTION

The behavior of a strip footing resting on sand slope is considered necessary for this research, where the obtained results will be taken as a reference for the comparison with the strip footing resting on sand slope system.

Hawkins et al.[11] mentioned earlier the recent technological advancement have substantially reduced the quantity of the CKD generated during the manufacturing processes. Over the years: further reduction in the CKD generation is not generally possible due to technical issues related to efficiency of the cement production process. Appropriate disposal of the CKD is a challenging problem in the cement industry due to environmental concerns. Exploring ways to use of CKD as a value-added product has been of great concern to the cement industry as a whole. The compositions of CKD are similar to that of cement, consisting of alumina, silica, calcium oxide alkalis and sulfates. However, the amount of alkalis and sulfates, calcium carbonate/calcium oxides are substantially higher in CKD compared to cement. The higher alkalinity and finer particle size, in addition to its cementations properties, make this material usable for several applications. Connor et al[7], McKay and Emery[13] published some of the potential uses of CKD, that take advantage of its favorable chemical and physical properties are waste solidification. The replacement for Portland cement in concrete block manufacturing and ready mix concrete and in supplementary cementations materials studding by (Bhatty [6], Zaman, Laguros and Sayah [25], Detwiler et al.[8], Udoeyo and Hyee[23], Al-Harthy et al [3], Hawkins et al.[11]), hydraulic barrier in a landfill liner/cover suggested by(Ballivy et al.[5]), land application as agricultural soil amendment suggested by (Santagata and Bobet[16], flow able fill suggested by (Miller and Azad [15], Katz and Kovler[12]), mineral filler in asphalt paving and mine reclamation, and sorbent to remove sulfur dioxide from cement kiln flue gas. Occasionally, Bhatty[6] studied the CKDs contain large amounts of free-lime (CaO) making it a potential candidate for substituting traditional soil stabilizer (lime), fertilizers, sludge stabilizers. Santagata and Bobet [16] Studies reported in the past have shown that treating soils with CKDs improves its various properties and hence some CKDs has great potential to be used as an effective soil stabilizer. The need for soil stabilization and the use of CKDs as potential stabilizers are reviewed in detail in the following sections.

Summary of Prior Stabilization Research

Compaction: Bhatty et al.[6] studied the Maximum dry unit weight (MDUW) and optimum moisture content (OMC) are altered with CKD treatment due to the ability of CKD to absorb water and alter soil structure through pozzolanic and cation exchange reactions. The effect on MDUW and OMC is not consistent throughout the previous studies. In most cases MDUW decreased and OMC increased with increased CKD treatment (Zaman et al.[26], Miller and Azad[15] and Sreekrishnavilasam[20]), but the reverse trend was observed by Baghdadi[4]. Maximum dry unit weight of granular soils tends to increase at lower CKD contents and decrease at higher contents tested by (Baghdadi and Rahman[4], Baghdadi et al.[3], Freer-Hewish et al.[10]). Taha[22]), observed an increase in MDUW with CKD content but is consistent with the aforementioned trend as the maximum CKD content was 20% by weight of aggregate. The increase in MDUW is attributed to pore-space filling as these materials contain few fines. The effect of CKD on OMC of granular soils is less clear. Freer-Hewish et al. [10], observed that OMC continuously increased with CKD content, while Baghdadi and Rahman [4] and Baghdadi et al. [3], observed that OMC decreased at low CKD contents and increased at high CKD contents.

Strength: Baghdadi and Rahman[14], Baghdadi et al.[3] and Freer-Hewish[10] studied experimentally Granular soils gain unconfined compressive strength UCS with CKD content. While some sand-CKD mixtures continuously gain strength up to very high CKD contents (75 to 100% by total dry weight, other granular materials peak or plateau at the relatively low CKD content of 15% by weight of the aggregate(Taha[22]). Soaking reduces UCS (Baghdadi et al.[3]). Baghdadi and Rahman[4] and Baghdadi et al.[3] demonstrated that CBR is improved with CKD treatment.

The present research concerns with rigid rough strip footings (rectangular footing with L/B ≥5). Footings are designed to transfer the superstructure loads safely to the underlying soils. Consequently, the soil should be able to carry the applied structural loads without under going either shear failure or excessive deformations.

Experimental Studies for the Bearing Capacity of a Footing Adjacent to a Slope

Shield and Garnierr [18] reported the results of controlled experiments to measure the ultimate bearing capacity of footings located at various locations within a granular slope, they used dense sand only in their tests and the footing locations were extended within the slope itself. Two different footing sizes were investigated and the load was applied to the footing in two forms, vertically and inclined at an angle of 15^o from the vertical towards the slope. The footing model was 0.3 m thick and 0.6 m wide and 2 m long. The sand box was 2 m wide, 2 m high and 15 m long. The box was divided into two equal compartments. From the results of these tests, they obtained the bearing capacity factor ($N_{\gamma q}$) from the equation:-

$$N_{\gamma q} = \frac{2q_u}{\gamma B} \quad \text{...} \quad (1)$$

Shields, et al. [18] discussed the Gamperline's (1988) results of 215 tests, which were made on the model scale footing located at the top of slope on cohesionless soil. The range of tests varied from (b/B=0 to 2.5), and (D_f / B = 0 to 1),

Where:

b = Footing edge distance from the crest of slope.

Gamperline's tests were performed in a centrifuge at a number of different gravity forces (g).The effective breadth of the footings varied from 0.61 m to 1.83 m. Note that only footings with a positive b value were involved (i.e. footing resting adjacent to a slope). In all cases the footings were subjected To a vertical, centric load.

Two different slope angles, β=26.6° and β=33.7°, were investigated. Nine different sand densities were employed. Based on 215 tests, Gemperline proposed a general equation for determining the bearing capacity factor $N_{\gamma q}$ that is used instead of $N_{\gamma q}$ (for horizontal ground only) in Meyerhof's bearing capacity equation. Gemperline proposed a new equation for determination $N_{\gamma q}$ for footing resting adjacent to a slope. The Gemperline equation is written in the following form:

$$N_{\gamma q} = f(\phi) \times f(B) \times f(D_f / B) \times f(B / L) \times f(D_f / B, \; B / L) \times f(\beta, \; b / B) \times f(\beta, \; b / B, \; D_f / B) \times f(\beta, \; b / B, \; B / L) \text{.......... ....} (2)$$

Where B is in inches and the equation is invalid for β greater than 45°.

The Purpose of the Present Study

The present study can be summarized as:

(a) Footing /Slope System

Laboratory tests carried out on a small scale model. The main aims of this study are investigation the behavior of a rigid strip footing resting on sandy slopes. The investigation was carried out for a wide range of parameters such as the edge distance of the footing from crest of slope (b), the slope height (H), slope angle (β) and angle of internal friction (ϕ) as shown in Fig.(1).

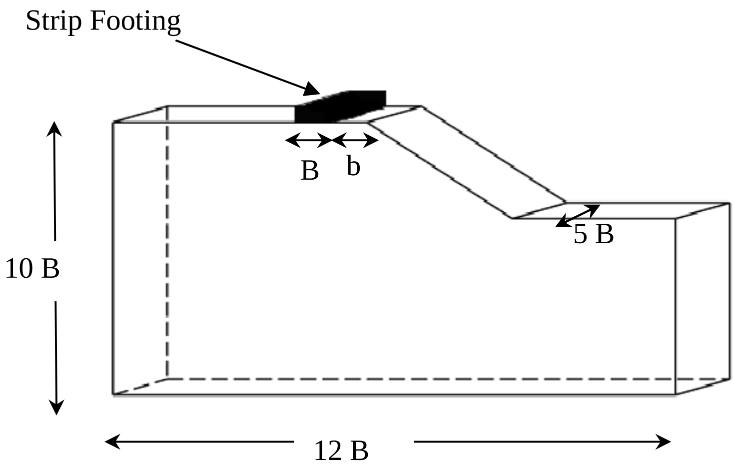


Fig.(1): Footing/slope system before immprovement

(b) Footing/Stabilized Slope System

In the present investigation a series of laboratory plane strain model tests carried out on a rigid strip footing resting on a stabilized sandy slope. A wide range of boundary conditions was examined by varying the design parameters. The investigation was carried out for a wide range of parameters such as the CKD percentage in mixtures, the edge distance of the footing from crest of slope (b), the slope height (H), slope angle (β) and angle of internal friction (ϕ) as shown in Fig.(2).

In addition, comparisons between the present investigation results and other investigations proposals will be presented.

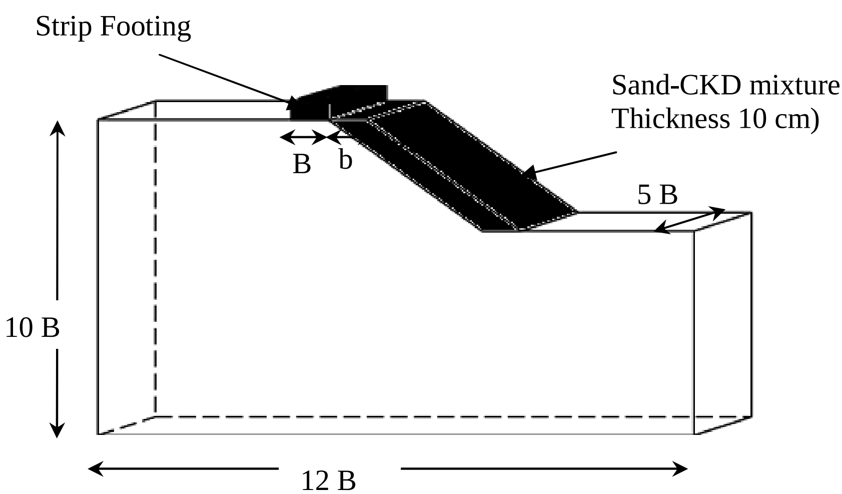


Fig.(2): Footing/slope system after immprovement

<u>The objectives of this part of study are summarized as follows:-</u>

1) The effect of different percentages of cement kiln dust adding on the engineering properties of the sand was investigated. The results show significant improvement in their engineering properties.
2) The main objective of this part of study is to investigate the stability of a rigid rough strip footing resting adjacent to a sandy slope.
3) Study the effect of footing location/footing width (b/B) beside the sand slope.
4) Study the effect of relative density on the stability sandy slope.

2. MATERIALS USED AND TESTING PROGRAM

2.1 Materials Used

The experimental tests of this paper presents are carried out on a small scale model of a footing resting on sandy slope system. Many parameters have been studied, such as the angle of slope (α) and the footing location, b (footing edge distance from the crest of slope), the slope angle, (β) and the angle of internal friction, (ϕ).

a) Grain Size Analysis of sand

The grain size analysis and main physical properties of the used sand were determined according to Egyptian Code [9]. Grain size analysis was performed on samples from the used sand. Figures (3) show the average grain size distribution of the used sand. It is found that the used sand is coarse to medium sand, and classified as well as well graded sand (SW) according to Unified Soil Classification System (USCS). The main physical properties of sand are given in Table (1).

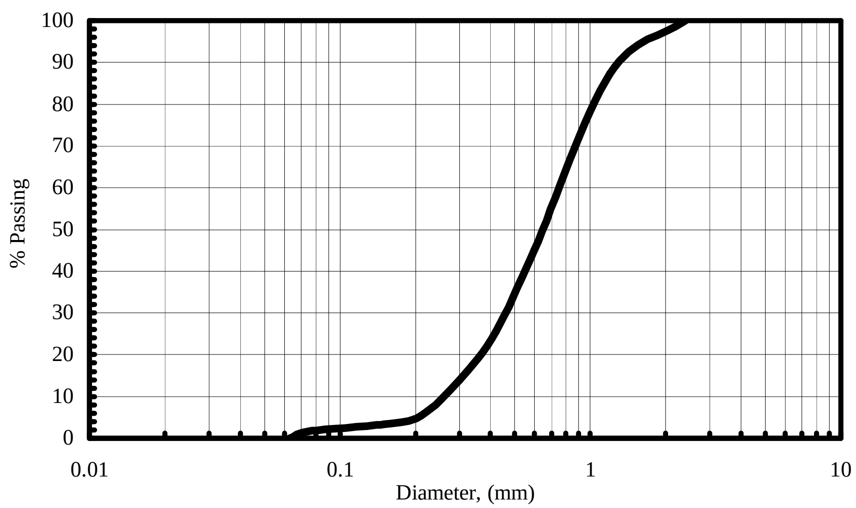


Fig. (3): Particle size distribution

b) Grain Size Analysis of CKD

The manufacture of Portland cement includes the tumbling of fine ground raw materials (75–80% passing a 200 mesh) inside a rotary kiln. The tumbling action releases fine dust particles that are quickly swept out of the kiln by the hot combustion gases. This dust, referred to as cement-kiln dust (CKD), is captured by particulate emission control equipment. As a result of the cooling associated with the dust capture, the CKD provides nucleation sites for minerals that are volatilized in the kiln system. are given in Table (2)

Table (1) Properties of sand

Parameter	Symbol	Relative density of sand			Unit
		60%	70%	82%	
Material model	Model	Mohr- C	Mohr- C	Mohr- C	----------
Type of behavior	Type	Undrained	Undrained	Undrained	----------
Unit weight	γ	17	17.4	17.9	kN/m^3
Young's modulus	E	8000	10000	12000	kN/m^2
Poisson's ratio	υ	0.35	0.3	0.27	----------
Friction angle	Φ	36	37	41	Degree
Dilatancy angle	ψ	6	9	12	Degree
Reduction	R_{inter}	0.9	0.9	0.9	----------

Table (2) : Properties of mixtures

Parameter	Symbol	Sand-CKD mixture			Unit
		CKD(10%)	CKD(20%)	CKD(30%)	
Material model	Model	Mohr- C	Mohr- C	Mohr- C	---------
Type of behavior	Type	Undrained	Undrained	Undrained	---------
Unit weight	γ	19.3	19.6	18.8	kN/m^3
Young's modulus	E	31000	40000	52000	kN/m^2
Poisson's ratio	υ	0.4	0.35	0.35	--------
Friction angle	Φ	26	20	19	Degree
Cohesion	C	8	25	40	kN/m^2
Dilatancy angle	ψ= Φ Φ<30	26	20	19	Degree
Reduction	R_{inter}	0.9	0.9	0.9	---------

2.2 Tank Model

The description of the used tank model (soil container) and factors which have been taken into consideration for manufacture will be discussed as follows:-

Soil Container

A rectangular steel tank with dimensions as shown in Fig. (4) and Photo (1) was used. All sides of the tank were made from steel plates with thickness 3 mm except the front side which was made from prespex of 10 mm thickness. The dimensions of the tank are to be chosen so that the tank boundaries have no influence on the test results. Therefore, the loading foundation zone affected the soil tank size, the extent and depth of footing pressure bulb influence the tank length and depth is discussed below. The pressure isobars of a strip extend laterally almost two times the loading foundation width (from the centerline of the foundation).

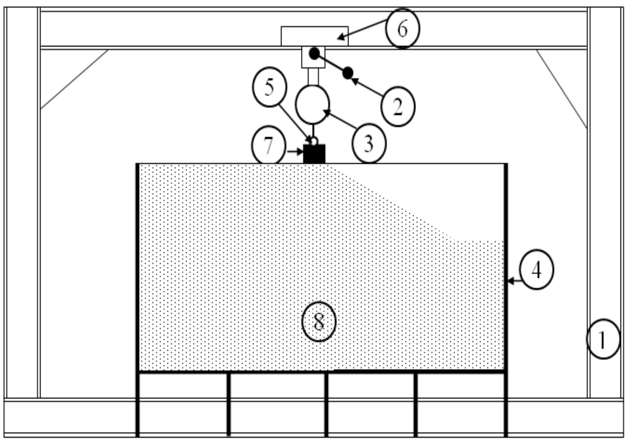


Fig. (4): The experimental apparatus drawing

1- Loading Frame 2- Manual Screw Jack 3- Proving Ring 4- Sand Container 5- Dial Gauges 6- Movable Head 7- Strip Footing Model 8- Sand

Therefore, a soil container with dimensions 1200 mm long, 500 mm width and 1000 mm deep was considered adequate for present study.

Photo. (1): Sand container (Tank model)

2.3 Test Procedure

Tests were carried out on one kind of soil (sand) to illustrate the deformations of slopes and improvement using cement kiln dust. This group concerns with carrying out an experimental test for the sandy slopes. The twenty seven tests were carried out with improvements for slope deflections. It reported in Table (3).

Table (3) Ratio of b/B and percentage of sand-CKD mixture with variable relative density

Test No.	b/B	CKD (%)	Relative density D_r(%) (sand)
1	0	10	60
2			70
3			82
4		20	60
5			70
6			82
7		30	60
8			70
9			82
10	1	10	60
11			70
12			82
13		20	60
14			70
15			82
16		30	60
17			70
18			82
19	2	10	60
20			70
21			82
22		20	60
23			70
24			82
25		30	60
26			70
27			82

2.4 Footing Settlements

It is important to know the magnitude of the settlement of footing needed to mobilize ultimate load. Skempton [19] observed that, in saturated clays the settlement may be about 3% to 7% of the footing width for footing. Somewhat higher values are found for footing in sand, they ranges from about 5% to 15% for footings as Vesic [24] and Ahmed [1]. This deviation is probably due to the settlement being influenced by many factors which include the footing width, the restraint on the footing horizontal movement and its rotation, and to a lesser extent on the rate of penetration of the footing as Vesic, et al. [24]. It is worth mentioning that the settlement ratio at ultimate load obtained in the present study is in a good agreement with the above values under approximately the same conditions

3. DISCUSSION AND EXPERIMENTAL WORK

The efficiency of the stabilization technique was studied by choosing three footing locations, b/B=0, b/B=1 and b/B=2. The relation between bearing capacity and settlement are plotted for different b/B and CKD percentage as shown in Figs. (5) to (13). From these figures, it can be concluded that:-

- The ultimate bearing capacity-settlement curves exhibit a defined failure point; this means that the modes of failure are general shear failure. This agrees with that obtained from experimental tests.
- The effectiveness of treated mixture is influenced by the method of specimen making and curing condition.
- The ultimate bearing capacity of the sandy slope increases as the CKD percentage increases in the mixture. Also the ultimate bearing capacity of the sandy slope increases with increasing (b/B) ratio.

The ultimate Bearing Capacity Due to CKD Percentage

The ultimate bearing capacity-cement kiln dust percentage relationships of the stabilization slope were derived from series of loading tests from experimental work. The comparison between q_u (kN/m^2) and CKD (%) is very important to know efficiency of stabilization slope with CKD. The efficiency of the stabilization technique was studied by choosing three footing locations, b/B=0, b/B=1 and b/B=2. The variations of ultimate bearing capacity and b/B are plotted as shown in Figs. (14) to (16).These figures show the relationships between the ultimate bearing capacity and CKD percentage with different footing locations. It can be noticed that the ultimate bearing capacity increases with the increasing of CKD. Also the ultimate bearing capacity increases with increasing the relative density of sand. Where the curve consisted of an upper curved part and a lower part, which is a straight line, it can be recognized that the increase of the ultimate bearing capacity for b/B=2 is greater than that for b/B=1 also the ultimate bearing capacity for b/B=1is greater than that for b/B=0 for the same stabilization stage. This leads to that, the need for using stabilization technique increases with the footing placed far the crest of slope. In these cases, the ultimate bearing capacity q_u, CKD curves exhibit a peak point, which defines the ultimate bearing capacity.

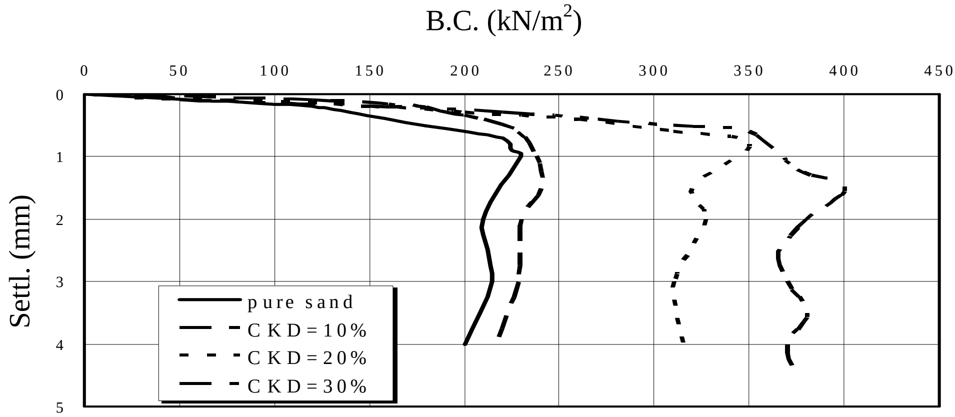


Fig. (5) Bearing capacity–settlement relationships for dense sand (b/B=0)

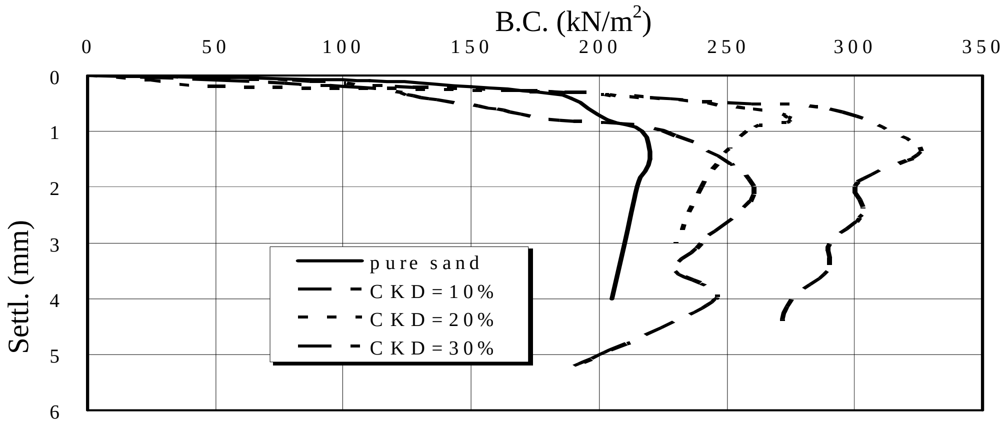


Fig. (6) Bearing capacity–settlement relationships for medium sand (b/B=0)

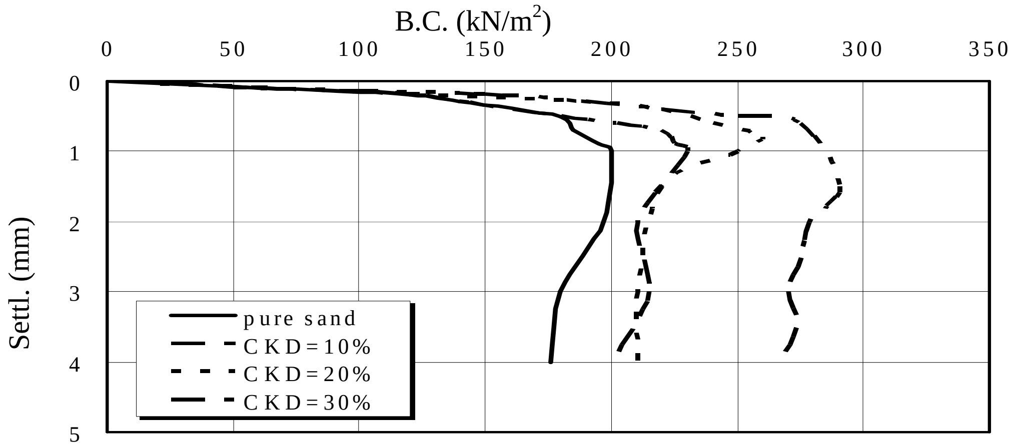


Fig. (7) Bearing capacity–settlement relationships for loose sand (b/B=0)

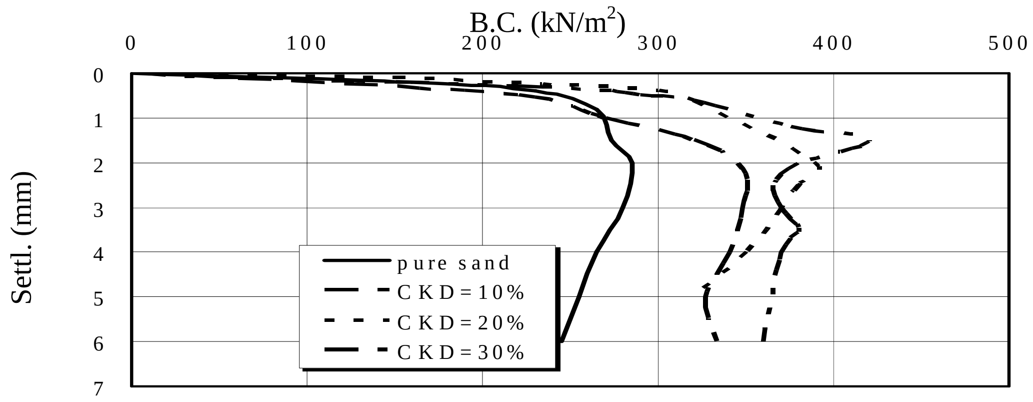


Fig. (8) Bearing capacity–settlement relationships for dense sand (b/B=1)

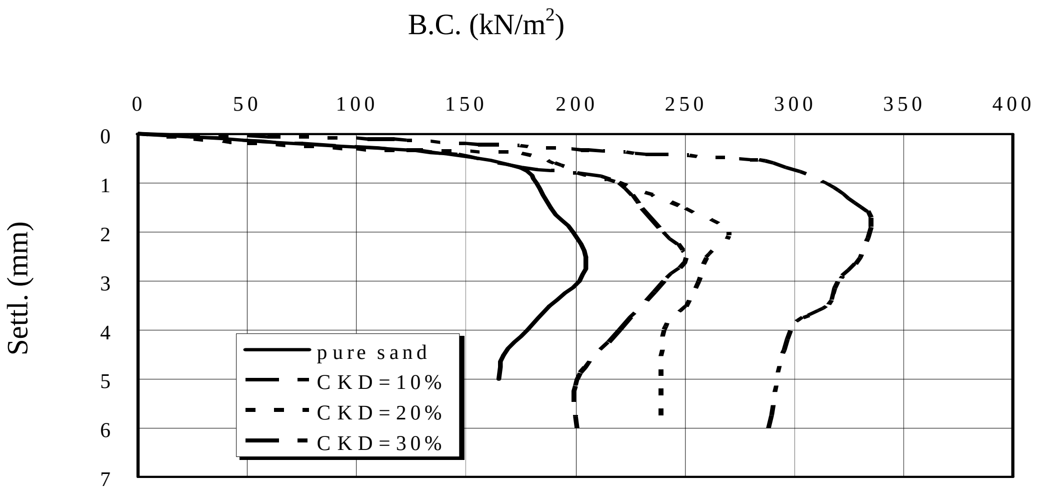


Fig. (9) Bearing capacity–settlement relationships for medium sand (b/B=1)

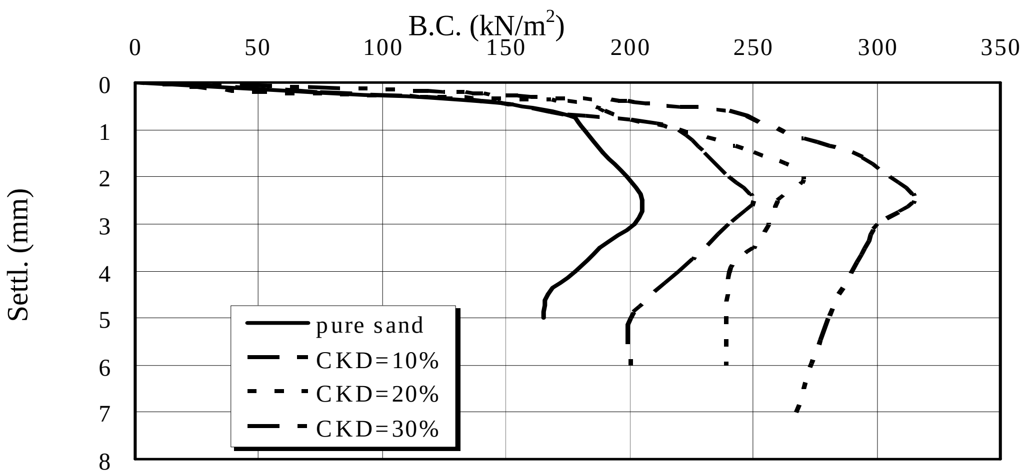


Fig. (10) Bearing capacity–settlement relationships for medium sand (b/B=1)

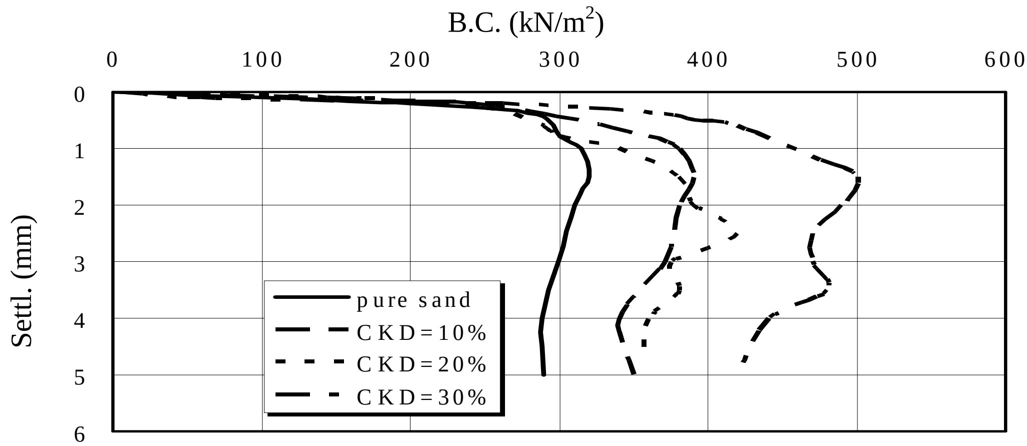


Fig. (11) Bearing capacity–settlement relationships for dense sand (b/B=2)

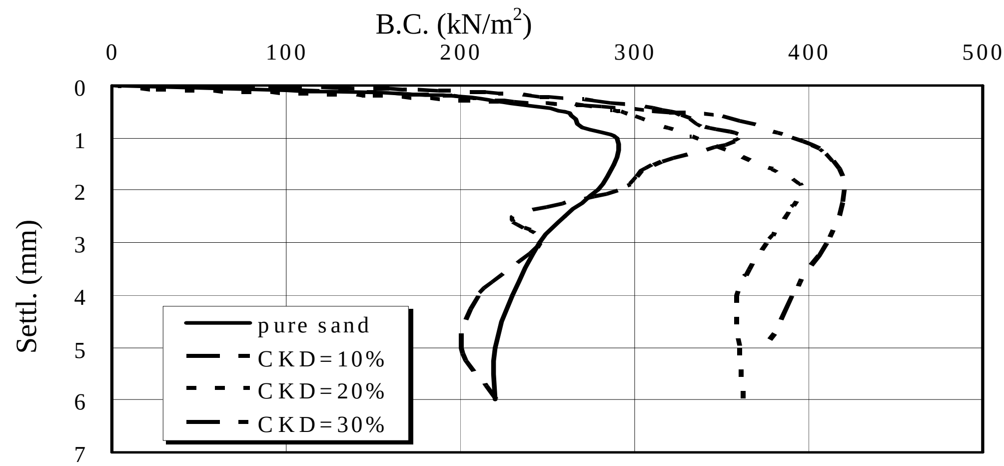


Fig. (12) Bearing capacity–settlement relationships for medium sand (b/B=2)

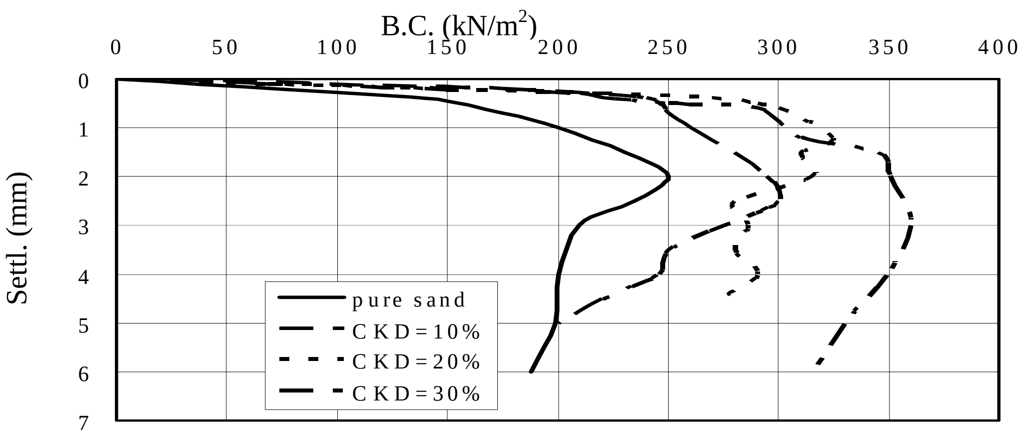


Fig. (13) Bearing capacity–settlement relationships for loose sand (b/B=2)

Figures (14) to (16) show the relationships between the ultimate bearing capacity q_u and CKD percentage (C), it can be noticed that the horizontal displacement increases with decreasing (C). The relationships can be represented as a straight line by equations (1), (2) and (3) and can be written as follows:

For b = 0

$q_u = 5.5\ C + 235$, $R^2 = 0.9902$, for $D_r = 82\%$

$q_u = 3.3\ C + 220.5$, $R^2 = 0.9637$, for $D_r = 70\%$ (1)

$q_u = 3\ C + 200$, $R^2 = 1$, for Dr = 60%

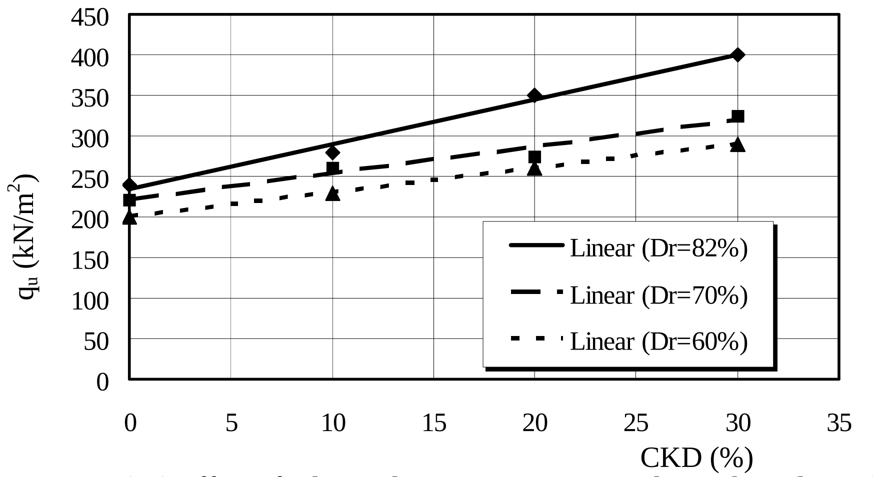


Fig. (14) Effect of relative density on CKD - q_u relationships (b/B=0)

For b = 1

$q_u = 4.45\ C + 294.5$, $R^2 = 0.9689$, for $D_r = 82\%$

$q_u = 3.5\ C + 232.5$, $R^2 = 0.9646$, for $D_r = 70\%$ (2)

$q_u = 3.5\ C + 207.5$, $R^2 = 0.98$, for $D_r = 60\%$

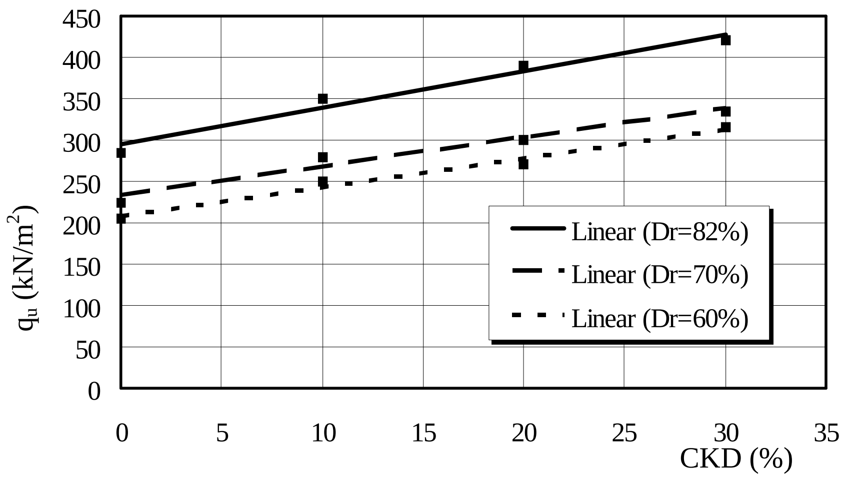


Fig. (15) Effect of relative density on CKD - q_u relationships (b/B=1)

For b = 2

$$q_u = 5.7\ C + 322,\quad R^2 = 0.9742,\quad \text{for } D_r = 82\%$$
$$q_u = 4.22\ C + 302.2,\quad R^2 = 0.947,\quad \text{for } D_r = 70\% \qquad (3)$$
$$q_u = 3.55\ C + 2.55,\quad R^2 = 0.9887,\quad \text{for } D_r = 60\%$$

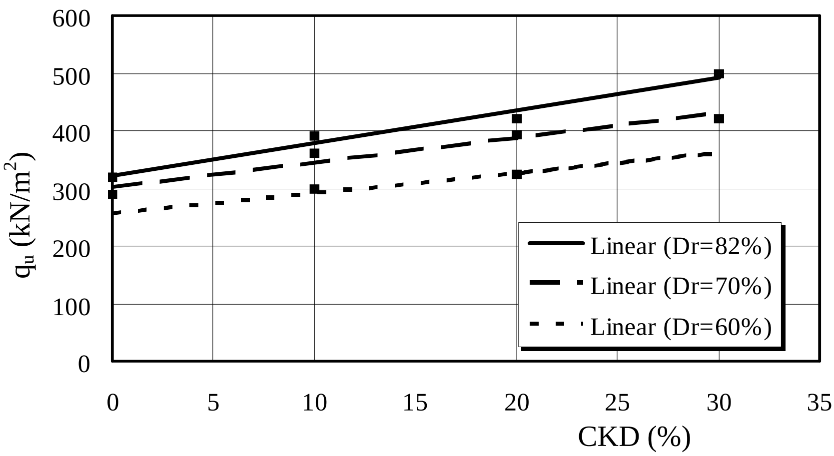


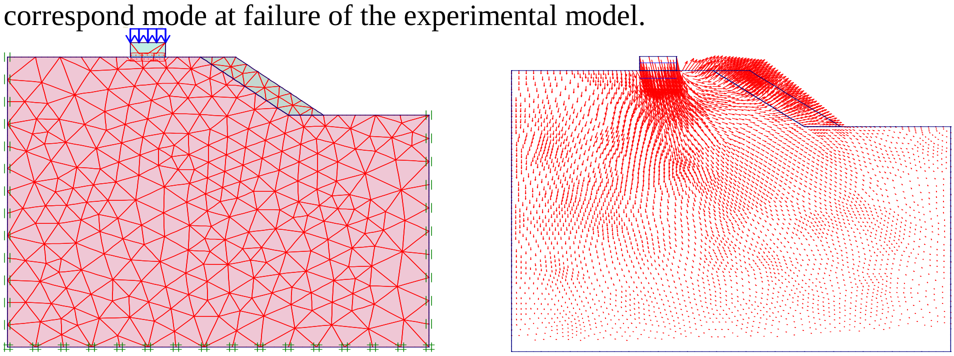
Fig. (16) Effect of relative density on CKD - q_u relationships (b/B=2)

Experimental and Numerical Modeling

The experimental model was simulated by the finite element method (FEM) using the computer program ***PLAXIS***. The evaluation of the numerical model results by the corresponding experimental model results should be done to emphasis the accuracy of the finite element model and the considered parameters. After evaluation, a wide range of parameters that were not investigated in the laboratory model were studied.

Numerical Model Evaluation

The finite element analysis was carried out for footing on stabilized slope system according to the conditions used in the analysis of footing on sandy slope system. A stabilization element was added to the previous numerical model. The interface friction angle was modeled by assigning the strength reduction factor (R_{int}) equal to 0.9. Fig.(17) illustrates mode of failure according to FEM and photo (2) illustrates the correspond mode at failure of the experimental model.



a) Before loading b) After failure

Fig.(17) Typical finite element model used in the analysis

a) Before loading b) After failure

Photo.(2) Experimental model used in the analysis

Results of the Evaluated Model

The results obtained from the numerical analysis and the corresponding experimental tests in terms of the bearing capacity (B.C.) and settlement (S) to evaluate the numerical model. From these figures, it can be concluded that:-

- The experimental tests are useful for verifying the parameters used for the numerical analysis such as the axial stiffness for stabilization slope, reference young's modulus (E_{ref}) and Poisson ratio (υ) for sand.
- The bearing capacity values obtained from the numerical analysis were less than these obtained from the experimental tests.
- The trend of the obtained curves from the numerical analysis is the same with that from the experimental tests.

Comparison between the ultimate bearing capacities attained by the experimental work and that attained by FEM for twenty seven pairs of experiments were plotted in Fig. (18). Form the figure can be noticed that $q_{u(EXP.)}$ is always bigger than $q_{u(FEM)}$ by a small value for the same test

The relationships between $q_{u(EXP.)}$ and $q_{u(FEM)}$ can be represented as a straight line by equations (1) and can be written as follows -

$$q_{u(FEM)} = 0.88\, q_{u(EXP)} + 5.3042 \qquad \text{......................(4)}$$

Where:-

$q_{u(EXP.)}$ = ultimate bearing capacities attained by the experimental work

$q_{u(FEM)}$ = ultimate bearing capacities attained by FEM

The coefficient of variation (R^2) in linear equation between computed and measured peak bearing capacity is 0.895. This high value of R^2=0.895 indicates a good correlation.

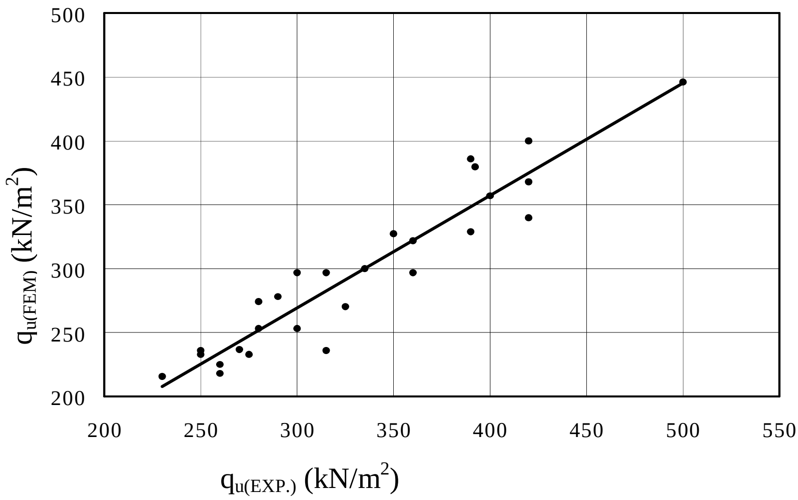


Fig. (18) Comparison between $q_{u(EXP.)}$ and $q_{u(FEM)}$ for twenty seven pairs of experiments

4. CONCLUSIONS

- An addion of CKD to sand will improve the compaction characteristics in a similar way to the treated soil with cement.
- The bearing capacity of the sandy slope increases as the CKD percentage increases in the mixture.
- The increase of the ultimate bearing capacity for b the edge distance of the footing from crest of slope (b)/footing width (B) equal to 2 is greater than that for the edge distance of the footing from crest of slope (b)/footing width (B) equal to 1 also the ultimate bearing capacity for the edge distance of the footing from crest of slope (b)/footing width (B) equal to 1is greater than that for the edge distance of the footing from crest of slope (b)/footing width (B)equal to 0 for the same stabilization stage. This leads to that, the need for using stabilization technique increases with the footing placed far the crest of slope.
- Deformations of the front of slide mass during down slope movement after improvement is approximately small.
- There is a good agreement between the experimental and the finite element analysis results of a strip footing resting adjacent to sandy slope; this emphasis's the accuracy of carrying out the experimental tests and the parameters used in the finite element analysis.

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دراسة عملية لإتزان الميول الرملية المعالجة بتراب الأسمنت تحت تأثير القواعد الشريطية

يهتم عديد من الباحثين في مجال هندسة البيئة وبعض المجالات الأخرى بكيفية الإستفادة من بعض المخلفات الصلبة الناتجة من الفرن الأسمنتي والتي تسبب بعض المشاكل البيئية والصحية وتؤثر علي البيئة الحيوية المحيطة ومن أهم هذه المخلفات التي تعرض لها البحث هو غبار الفرن الأسمنتي.

غبار الفرن الأسمنتي عبارة عن ناتج ثانوي من عمليات تصنيع الأسمنت البورتلاندي حيث يتكون أثناء حرق المواد الخام في الفرن المخصص لإنتاج الخبث. وفي هذا البحث حاولنا دراسة الإستفاده من هذا الناتج المخلف في تثبيت الميول المكونة من التربة الرملية.

وقد تناولت هذه الدراسة العملية إضافة نسب مختلفة من غبار الأسمنت علي الميول المكونة من التربة الرملية بأنواعها التي تم تشكيها معمليا بإستخدام أجهزه وطرق قياسية خاصة بذلك.

و من النتائج المعملية لوحظ تحسن خواص التربة الرملية الفيزيائية والكيميائية والميكانيكية وكذلك لوحظ أن قدرة تحمل التربة تزداد بزيادة نسب غبار الفرن الأسمنتي في الرمل وأيضا تحسنت خواص الدمك للتربة الرملية بزيادة القيمة العظمي للكثافة الجافة وزادت قدرة تحمل التربة بزيادة المعدل الزمني.

ونظرا لأهمية الدراسة العددية وتكاملها مع الدراسة المعملية ، تم استخدام برنامج الحاسب الألى (PLAXIS) ، وهو يعتمد على طريقة العناصر المحددة (FEM) لتمثيل الأساس المرتكزعلى ميول رملية المعالجة بغبار الفرن الأسمنتي، حيث تم ادخال بعض المعاملات الخاصة بالتربة وتطويع هذا البرنامج لعمل اتزان الميول الرملية المعالجة وتم مقارنتها بالنتائج المعملية ووجد ان هناك توافق شديد في هذه النتائج.