# BEARING CAPACITY OF SHALLOW FOOTING ON SOFT CLAY IMPROVED BY COMPACTED CEMENT DUST

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**ABSTRACT**

Low bearing capacity of weak soil under shallow footings represents one of construction problems. Kaolin with water content converges to liquid limit used to represent the weak soil under shallow footing prototype. On the other hand, cement dust, which can be defined as undesirable industrial waste material come from cement industry, was used to improve the bearing capacity of the soft soil considered in this research. The soft soil was prepared in steel box (36×36×25) cm and shallow square footing prototype (6×6) cm were used .Group of physical and chemical tests were conducted on kaolin and cement dust. The improvement were performed by making trench under the footing filled with compacted cement dust (at its optimum moisture content) at three depths (D=B, D=2B, D=3B), the trench had the same footing Dimensions, note that (B) represent the footing width. Pressure-settlement curves were used to predict the ultimate bearing capacity. The improvement ratio in bearing capacity was calculated by comparing the ultimate bearing capacity value when testing the kaolin alone with its value of kaolin improved with compacted cement dust at the same value of eccentricity. It is important to note that eccentricity values were chosen according to the rule of middle third of footing base(i.e.,e≤B/6). The improvement ratio was about (197%) in average value, that represent a good ratio of improvement.

**الخلاصة**

تمثل قابلية التحمل الواطئة للترب الضعيفة اسفل الاسس الضحلة من أهم مشاكل الانشاء. استخدمت تربة الكاؤولين بمحتوى رطوبة يقترب من حد السيولة لتمثيل التربة الضعيفة اسفل نموذج الاساس الضحل كما تم استعمال مادة غبار السمنت وهي من مواد المخلفات الصناعية التي تنتج من عملية صناعة الاسمنت وبكميات كبيرة تم استعمالها في تحسين قابلية تحمل التربة الضعيفة الممثلة بمادة الكائولين التجاري في هذا البحث.تم تحظير التربة داخل صندوق من الحديد بأبعاد( 36×36×25)سم مع نموذج لاساس مربع ضحل(6×6)سم . أجريت مجموعة من الفحوص الفيزيائية والكيميائية لمادة الكائولين ومادة غبار السمنت وتمت عملية التحسين من خلال عمل شق اسفل انموذج ألأساس الضحل وبنفس طول وعرض ألأساس وتم حدل مادة غبار السمنت فيه (عند محتوى الرطوبة ألأمثل) ولثلاثة اعماق مختلفة (D=B,D=2B,D=3B)، علما ان B تمثل عرض ألأساس.أ جريت مجموعة من فحوص التحميل

على التربة قبل وبعد التحسين وبتحميل مركزي ولامركزي مع الأخذ بنظر الأعتبار قاعدة منتصف ثلث قاعدة الأساس اي (e≤B/6)في التحميل اللامركزي.

أستخدمت العلاقة بين الضغط المسلط على الأساس مع الهبوط الحاصل في الأساس لإيجاد مقاومة التحمل القصوى للتربة تحت تأثير الاحمال المسلطة ولكل انواع الفحوص. تم احتساب نسية التحسين في مقاومة التحمل من خلال مقارنة مقاومة التحمل القصوىلتربة الكاؤولين بمفردها مع مقاومة التحمل القصوى لتربة الكاؤولين مع مادة غبار السمنت ولنفس مسافة التحميل اللامركزي .اعتمد البحث على عدة معادلات خطية تقريبية لتفسير النتائج العملية للفحوص، وصل معدل نسبة التحسين الى (197%) وهو ما يعتبر نسبة تحسين جيدة بالنسبة الى مقاومة التحمل.

**KEYWARDS: bearing capacity, improvement of soft clay, cement dust, shallow footing, eccentric loading**

## INTRODUCTION

Many researchers studied the improvement and stabilization of soft soil using different methods and procedures.

Khdhair (1997) used one type of stabilization which was carried out on Nasriyia sand dunes by cement dust, he made an experimental set up consisting of a wind tunnel that was designed and manufactured, and tests were performed to check the suitability of this material. Three different suspensions were prepared at a constant concentration with different mix ratios of cement dust and Portland cement.

The satisfactory results were obtained from using cement in a ratio of (90% cement dust + 10% portland cement) suspended in water in concentration of 0.33kg of this material for each liter of water applied to sand at $10\ell/m^2$ rate

Chakrabrti and Bhandri (2004) worked on improvement of settlement behavior and vertical stress dispersion of soft clay using compacted pulverized fuel Ash. They showed in most of cases the ground improvement becomes expensive, increasing the total project cost. Pulverized fuel Ash (PFA) is waste material from thermal power plants and creates problems during its disposal. The research was conducted using normally consolidated commercial kaolin (soft clay) in a test tank and the transfer of load to the soft clay was arranged through a model footing. It was revealed from the results that the improvement of load carrying capacity could be remarkably increased, using compacted PFA layer on soft clay. The percentage of improvement of bearing capacity has been revealed in two ways. The first by increase of diameter wells with the depth of compacted PFA, though the improvement is more in case of increment of depth (Z) of PFA bed, rather than increment of diameter ($D'$). The percentage of improvement of bearing capacity, for different depths and diameter of compacted PFA varies from 12 to 390. The stress dispersion was also improved for different depths and diameters of compacted PFA bed.

Deschamps (1998) used FBC and stoker Ashes as roadway fill. It was noticed that approximately 100,000 $m^3$ of atmospheric fluidized bed combustion (FBC) ash and stoker ash were used as structural fill in the construction of a large roadway embankment. The embankment is ~ 200 m long and 10m high, and it supports an extension of a street across a gravel quarry in waste Lafayette, Ind. An over view of the project and construction operation is described, and the results of geotechnical laboratory tests and field monitoring presented. Instruments used in the monitoring of fill behavior include settlement plates, vertical and horizontal inclinometers, seismic cross-hole tests, and preconstruction standard penetration tests.

Consequently, the cement dust material was used in stabilization but not used in improvement of soft clay, therefore; an idea was started to use this material in improving the bearing capacity of shallow footing on soft clay.

## MATERIAL PROPERTIES

### Kaolin

The kaolin clay used in this research was of commercial grade. It was from North of Hussainiat, AL-Anbar Governorate, Iraq.

Physical properties of kaolin, shear strength and compressibility parameters could be shown in **Table 1**

**Table 1** Physical properties, shear strength and compressibility parameters of kaolin

| Property | Value | Type of test | Standard |
|---|---|---|---|
| LL% | 44% | Atterberge limits | *ASTM 4318* |
| PI | 25% | | |
| $G_s$ | 2.77 | Specific gravity of solids | *ASTM D854* |
| $e_o$ | 0.819 | Standard Consolidation test | *ASTM D2435* |
| $n$ | 0.45 | | |
| $Cc$ | 0.34 | | |
| $\phi_u$ | 0 | Unconfined compression test | *ASTM 2166* |
| $C_u$ | 13 kPa | | |
| $C_v$ | $5.608*10^{-8}$ $m^2/s$ | Standard Consolidation test | *ASTM D2435* |

It was obvious from results shown in **Table 1** that the clay was classified as low plasticity clay (CL) according to the Unified soil classification system.

Chemical tests were carried out on kaolin with assistance of the state of geologic surveying and mining and the chemical composition of kaolin can be shown in **Table 2**

**Table 2** Chemical composition of kaolin

| **Chemical composition** | | | | |
|---|---|---|---|---|
| L.O.I.* | $TiO_2$ | $Fe_2O_3$ | $SiO_3$ | $Al_2O_3$ |
| 13.4-15.1% | 1.4-2.96% | 0.5-1.96% | 38-45% | 35.5-41.4% |

*L.O.I: Loss of Ignition

White kaolin which selected was provided by (The state of geologic surveying and mining) from Dewielca lies in the west of Iraq.

**Cement Dust**

The cement dust provided from cement factory of Al-Kuffa, Najaf Governorate, Iraq. Specific gravity test, standard Proctor and direct shear test were conducted on cement dust. The results are shown in **Table 3**

**Table 3** Results of physical, standard Proctor and direct shear test for cement dust

| Material Properties | Value | Type of test | standard |
|---|---|---|---|
| LL | 28% | Atterberge limits | *ASTM 4318* |
| PL | NP | | |
| $G_s$ | 2.66 | Specific gravity | *ASTM D854* |
| $\gamma_{d\ max}$ | 18.5 kN/m$^3$ | Standard Procter test | *ASTM D698* |
| $\omega_{opt.}$ | 25% | | |
| $C_u$ at $\omega_{opt.}$. | 50kPa | Direct shear test | *ASTM D3080* |
| $\phi_u$ at $\omega_{opt.}$. | 29$^o$ | | |

Chemical tests were conducted for cement dust with the assistance of NCCLR. The results could be shown in **Table 4**

**Table 4** Results of chemical tests for cement dust

| | |
|---|---|
| $SO_3$ % | 4.11 |
| Organic matter % | 0.22 |
| $CaCo_3$ % | 49 |
| Cl % | 0.04 |
| pH | 7.22 |

**EXPERIMENTAL WORK**

In order to simulate the behavior of shallow footing on weak soil, special techniques were used to achieve this purpose. These techniques include the manufacturing of steel box having the dimensions (36×36×25) cm.This box was filled with kaolin prepared at water content near its liquid limit. Also,a steel plate of (6×6 × 0.5)cm was used to simulate the shallow footing. A trench was made under the footing that resting on soft kaolin. The trench had the same dimensions of footing and excavated at different depths (D=B, D=2B, D=3B), where B represents footing width. Then, the trench filled with compacted cement dust (at its optimum moisture content) to the desired depth. **Fig. 1** shows a simple section in model loading test and the detail of footing and cement dust column which support it.

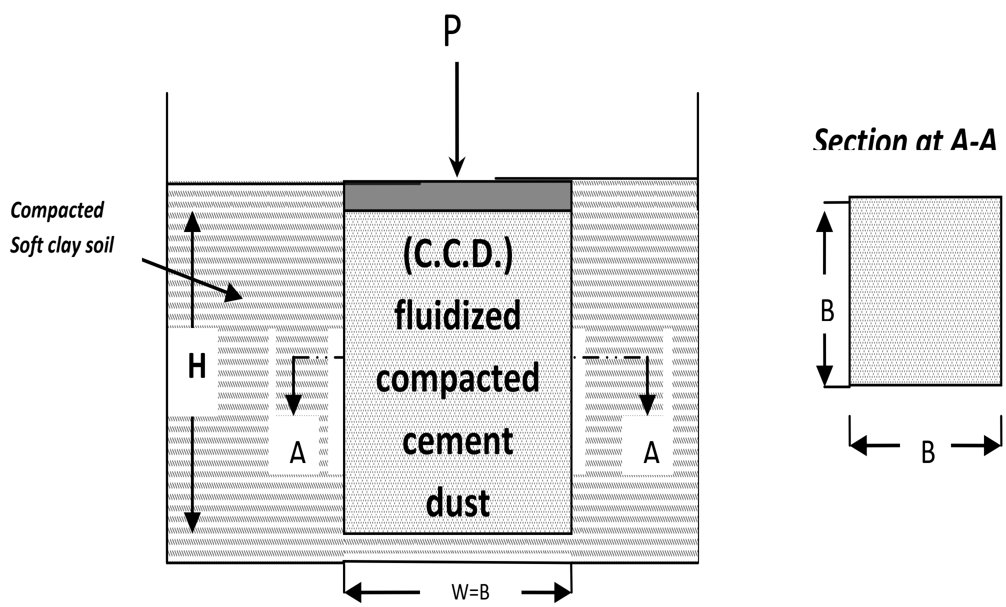



**Fig.1** Rectangular footing on **C.C.D.,** note that: width of compacted cement column **C.C.D.** =W, width of footing = B, W=B

Then, the footing is loaded at the beginning of the test until failure is reached. The settlement at centre and edge of the footing is recorded with the use of video camera.

### Compacted cement dust (C.C.D.)

The cement dust was prepared at optimum moisture content ($\omega_{opt..}$=25%) three depths of C.C.D. (H=6,H=12,H=18cm) were used. The sample of soft soil was prepared by putting the first layer of kaolin .Then; scaled steel mold was put and centered in length and width of steel box at the desirable depth which worked on. Then the trench under the footing was filled with compacted cement dust at its maximum dry density and optimum water content. It is compacted to the desired depth.

### Results of load –settlement tests

Typical load (kN) vs. foundation settlements at edge and centre of foundation diagrams were obtained from loading tests as shown in **Fig.2** to **Fig.4**. The ultimate bearing capacity is defined as the point where a maximum value of $q_u$ is clearly arrived, or where slope $\Delta s/\Delta q$ becomes maximum and the load vs. settlement not remains practically linear thereafter Vesic (1973).

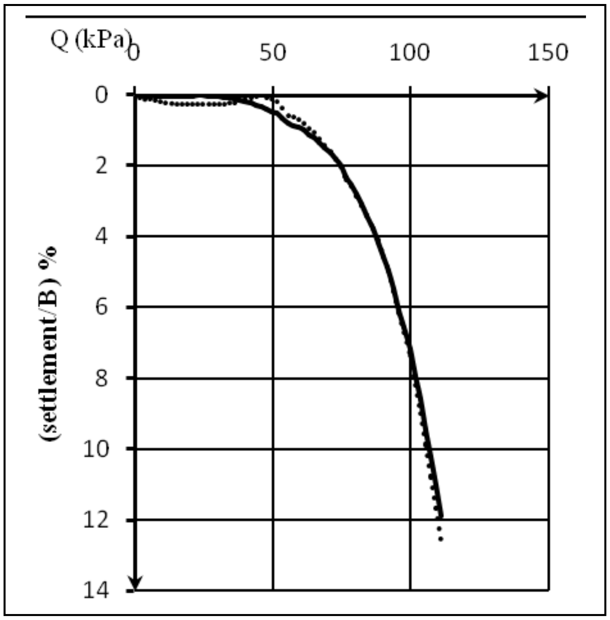



**Fig.2** Pressure-settlement ratio curve for kaolin with cement dust (H/B=1), concentric loading

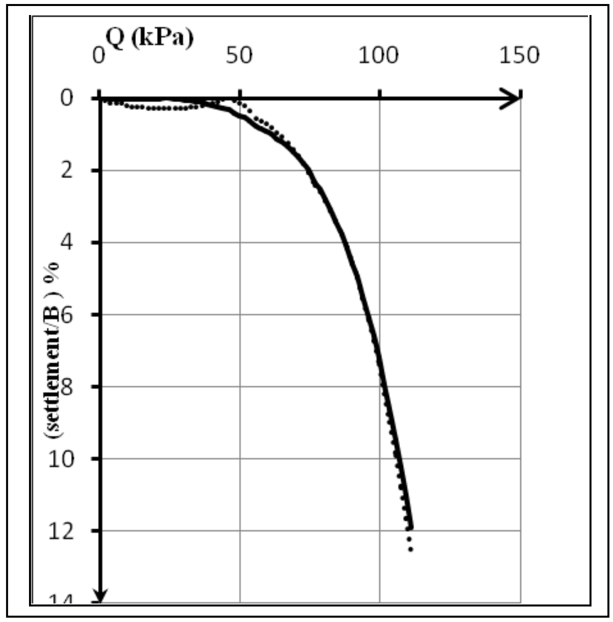



**Fig.3** Pressure-settlement ratio curve for kaolin with cement dust (H/B=2), concentric loading

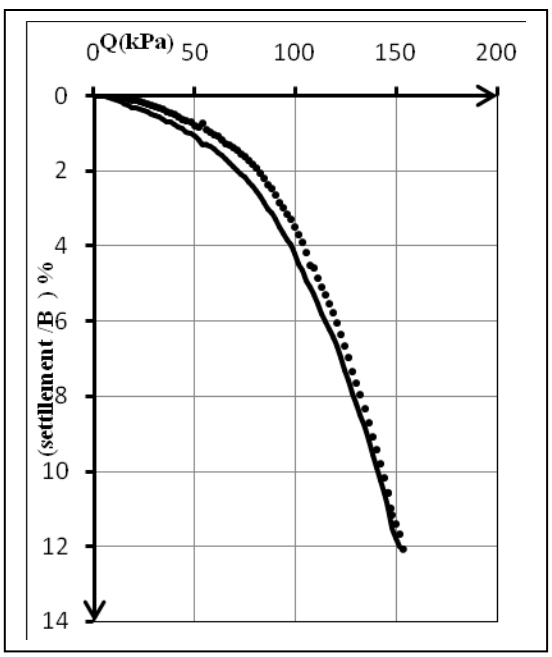
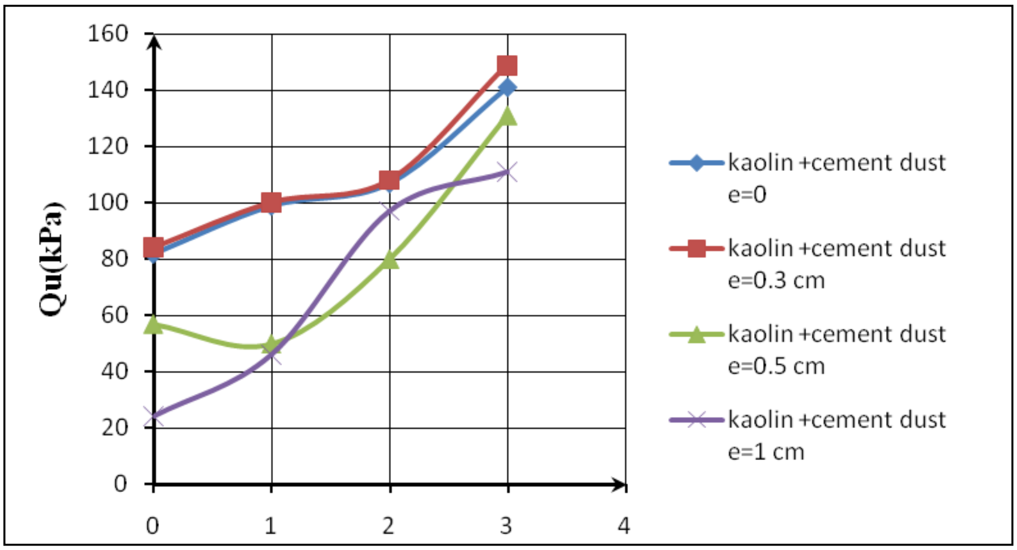



**Fig.4** Pressure-settlement ratio curve for kaolin with cement dust (H/B=3), concentric loading

**Effect of (H/B) ratio on Bearing Capacity**

In general, the ultimate bearing capacity incrased as H/B ratio increased. This behavoir was expected due to the increase in strength of soil under the footing as the (H/B) ratio, of the cement dust used for improvement, increased . In addtion, the ratio of improvement increased as the (H/B) ratio increased . The largset ratio of improvement getten for soil improved by cemnent dust at H/B=3,see **Fig.5** and **Table 4** . This behavoir may be explained accoring to the shear strength prameters, where the cohesion and angle of internal friction of cement dust were (50 kPa, $29^0$) respectively.




**H/B**

**Fig.5** Ultimate bearing capacity – H/B ratio relation

**Table 4** Type of the tests and the ultimate bearing capacity values

| Type of material used | Qu(kPa) | H/B | e(cm) | percent of improvement ratio% | Test No. |
|---|---|---|---|---|---|
| kaolin | 82 | 0 | 0 | 0 | 1 |
| kaolin +cement dust | 99 | 1 | 0 | 21 | 2 |
| kaolin +cement dust | 107 | 2 | 0 | 30 | 3 |
| kaolin +cement dust | 142 | 3 | 0 | 73 | 4 |
| kaolin | 84 | 0 | 0.3 | 0 | 5 |
| kaolin +cement dust | 100 | 1 | 0.3 | 19 | 6 |
| kaolin +cement dust | 108 | 2 | 0.3 | 29 | 7 |
| kaolin +cement dust | 149 | 3 | 0.3 | 77 | 8 |
| kaolin | 57 | 0 | 0.5 | 0 | 9 |
| kaolin +cement dust | 50 | 1 | 0.5 | -12 | 10 |
| kaolin +cement dust | 80 | 2 | 0.5 | 40 | 11 |
| kaolin +cement dust | 131 | 3 | 0.5 | 130 | 12 |
| kaolin | 24 | 0 | 1 | 0 | 13 |
| kaolin +cement dust | 46 | 1 | 1 | 92 | 14 |
| kaolin +cement dust | 98 | 2 | 1 | 308 | 15 |
| kaolin +cement dust | 111 | 3 | 1 | 363 | 16 |

**Effect of Eccentricity on Bearing Capacity**

The eccentricity has large effect on ultimate bearing capacity. Generaly the ultimate bearing capacity decreased as the eccenricity increased as shown in figure **Fig.5** .This behavior may be attributed to the reduction in effictive area as eccentrisity increased.

**Improvement ratio in the ultimate bearing capacity**

Foundation was reaching to failure if the settlement would be greater than (10%) from footing width, ASTM (D1194-94) so the bearing capacity at this ratio was equal to the ultimate bearing capacity. **Fig.6** shows the variation of improvement ratio with eccentricity at different (H/B) ratios. It is important to know that the improvement ratio is defined as:-

$$\text{Ratio of improvement (r) \%} = \frac{Q_{improved} - Q_{without\ improvement}}{Q_{without\ improvement}} * 100\ \%$$

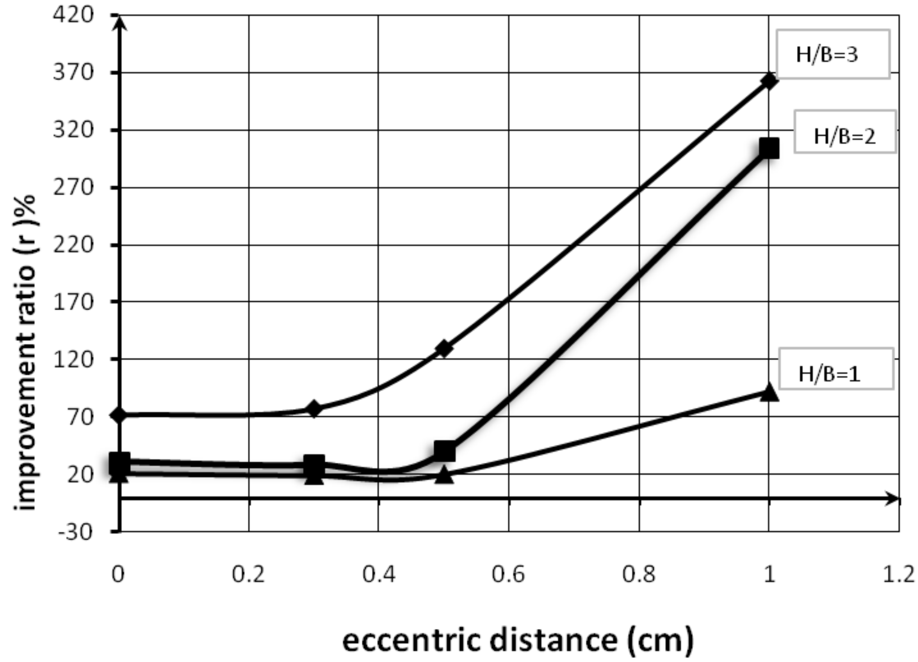



**Fig.6** Ratio of improvement and eccentricity relationship at different values of H/B, "kaolin-cement dust"

**Fig.7** gave the clear effect of (C.C.D.) depth on the ultimate bearing capacity. The maximum improvement ratios were appeared at (H/B) ratio equal to (3).

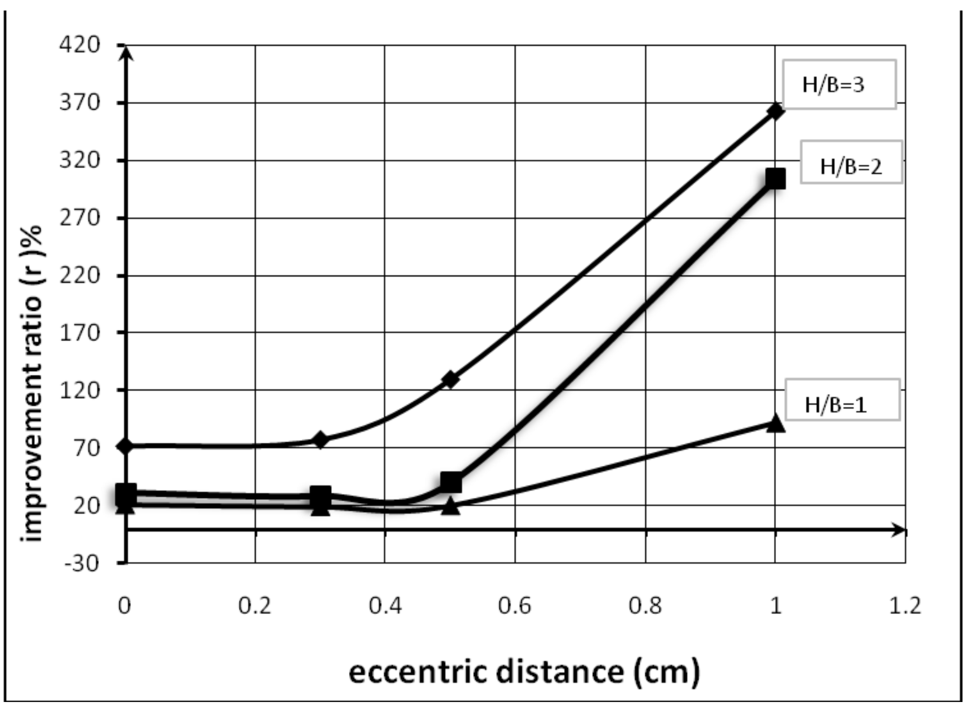



**Fig.7** Ratio of improvement and eccentricity relationship at different values of H/B ratio, "kaolin improved by cement dust"

**Equations obtained from experimental results**

Ratio of improvement in bearing capacity for cement dust used in improvement at different values of eccentricity were varied with the change in H/B ratio ,see **Fig.8**. In general, acceptable equations were obtained that simulate the incrase in r % with incrase of the H/B ratio for different values of eccentricity.

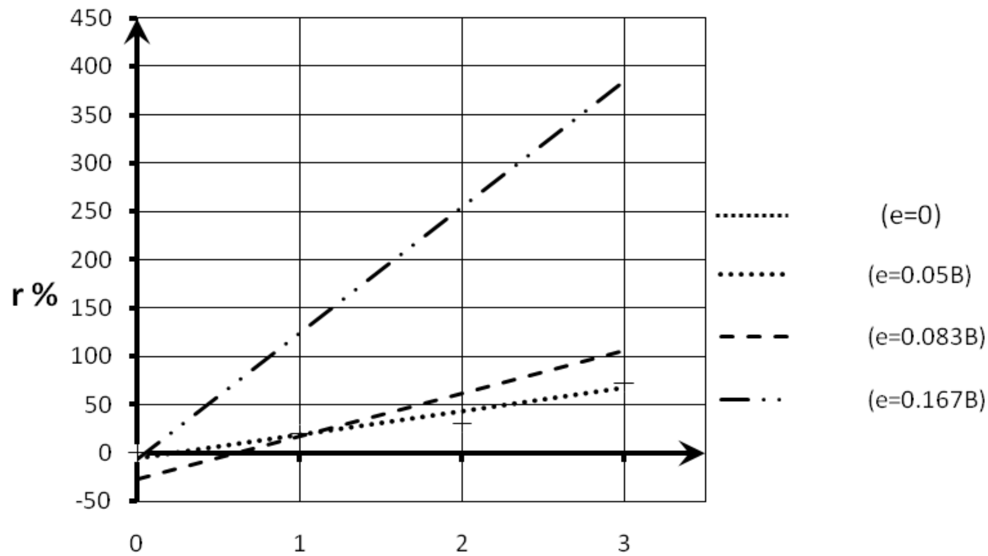



**Fig.8** Ratio of improvement and H/B relationship at different values of eccentricity, "kaolin improved by cement dust

**Table 5** shows the all equations can be use to predict the improvement ratio for any (H/B) ratio given, all equations was linear and have acceptable values of ($R^2$) (difference between the experimental results and the fitting equation results).

**Table 5** Predicted equations for estimating improvement ratio from depth ratio

| Type of material and test | Equations | $R^2$ |
|---|---|---|
| Kaolin+ cement dust , e=0 | r %= 24(H/B) -5 | 0.895 |
| Kaolin+ cement dust, e=0.05B | r %= 24(H/B) -5 | 0.895 |
| Kaolin+ cement dust, e=0.85B | r %= 44(H/B) -27 | 0.788 |
| Kaolin+ cement dust, e=0.167B | r %= 130(H/B) -5 | 0.954 |

**CONCLUSIONS**

Number of laboratory loading tests of shallow square footing supported by **(C.C.D.)** columns made in soft clay have been presented, based on the these results the following conclusions can be drawn:-

- There are acceptable improvement ratios for square footing prototype can be obtained (370%) in maximum value and (119%) in minimum value of improvement ratio(r %).
- Bearing capacity of soft soils under the shallow footing can be increased by making square trench under the footing with the same dimensions of it and for different depths. This trench is filled with compacted cement dust at optimum water content.
- The maximum improvement ratios in ultimate bearing capacity was appeared at maximum values of the (H/B) ratio which equal to (3).
- More acceptable ratios can be used for (H/B) ratios less than (3).
- Many fitting equations were obtained to estimate the improvement ratio from H/B ratio,all equation are linear and have acceptable values of ($R^2$).

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**NOTATIONS**

| Symbol | Meaning |
|---|---|
| C.C.D. | Compacted cement dust |
| $C_u$ | Undrained shear strength |
| H/B | Ratio between the depth of cement dust column to the footing width |
| L.O.I | Loss Of Ignition |
| NCCLR | National Centre of Construction Laboratories |
| PFA | Pulverized fuel Ash |
| $Q_u$ | Ultimate bearing capacity |
| $R^2$ | difference between the experimental data and fitting equation |
| r % | Improvement ratio in ultimate bearing capacity |