BEARING CAPACITY OF SHALLOW FOOTING ON SOFT CLAY IMPROVED BY COMPACTED FLY ASH

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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, fly ash, which can be defined as undesirable industrial waste material, 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 fly ash. The soft soil was improved by a bed of compacted fly ash placed under the footing with dimensions equal to that of footing but with different depth ratios. The results show that there is a noticeable improvement in the behavior of footing when improved by compacted fly ash. The improvement showed a decrease in settlement and increase in 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 fly ash 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 (130%) 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 الفحم المتطاير وهـي مـن مـواد المخلفات الصناعية . تم استعمالها في تحسين قابلية تحمل التربة الضعيفة الممثلة بمادة الكائولين التجاري في هذا البحث.تم تحظير التربة داخل صندوق من الحديد بأبعاد(٣٦×٣٦×٢٥)سم مع نموذج لاساس مربع ضحل(٦×٦)سم . أجريت مجموعة من الفحوص الفيزيائية والكيميائية لمادة الكائولين ومادة الفحم المتطاير وتمت عملية التحسين من خلال عمل شق اسفل انموذج ألأساس الـضحل وبنفس طول وعرض ألأساس وتم حدل مادة الفحم المتطاير فيه (عنـد محتـوى الرطوبـة ألأمثـل) ولثلاثـة اعمـاق مختلفـة (D=B,D=2B,D=3B)، علما ان B تمثل عرض ألأساس.أ جريت مجموعة من فحوص التحميل على التربة قبل وبعد التحـسين 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 للتربـة تحـت تأثير الاحمال المسلطة ولكل انواع الفحوص. تم احتساب نسبة التحسين في مقاومة التحمل من خـلال مقارنـة مقاومـة التحمـل القصوىلتربة الكاؤولين بمفردها مع مقاومة التحمل القصوى لتربة الكاؤولين مع مادة الفحم المتطـاير ولـنفس مـسافة التحميـل اللامركزي .اعتمد البحث على عدة معـادلات خطيـة تقريبيـة لتفسير النتـائج العمليـة للفحـوص، وصـل معدل نـسبة التحـسين الـى حـوالي (١٣٠%) وهو ما يعتبر نسبة تحسين جيدة بالنسبة الى مقاومة التحمل.

Keywards: bearing capacity, improvement of soft clay, fly ash, shallow footing, eccentric loading

Introduction

the transfer of load to the soft clay was arranged through a model footing. It was revealed from the Many researchers studied the improvement and stabilization of soft soil using different methods and procedures.

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 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.

MAERITAL 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**

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**

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

Fly ash

The fly ash used in this research was from station of south Baghdad electricity ,Baghdad ,Iraq. Specific gravity test, standard Proctor and direct shear test were conducted on fly ash. The results are shown in **Table 3** .

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

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 fly ash (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 fly ash column which support it.

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 fly ash (C.F.A)

The fly ash was prepared at optimum moisture content ($\omega_{opt..}$=24%) three depths of C.F.A. (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 fly ash 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 Δs/Δq becomes maximum and the load vs. settlement not remains practically linear thereafter Vesic (1973).

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 fly ash 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 fly ash 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 (5 kPa, 30^0) respectively.

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.6** .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.5** 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:-

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

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.

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).

CONCLUSIONS

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

1. There are acceptable improvement ratios for square footing prototype can be obtained (233%) maximum value of improvement ratio(r %).
2. 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 fly ash at optimum water content.
3. The maximum improvement ratios in ultimate bearing capacity was appeared at maximum values of the (H/B) ratio which equal to (3).
4. Acceptable ratios can be used for (H/B) ratios less than (3).
5. Many fitting equations were obtained to estimate the improvement ratio from H/B ratio, most of equation are linear and have acceptable values of (R^2).

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ASTM D1194-94 Standard Test Method for Bearing Capacity of Soil for Static Load and Spread footings.

ASTM D2166-80 Standard Test Method for Unconfined compression Test of Soils.

ASTM D2435-80 Standard Test Method for Standard Consolidation Test of Soils.

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NOTATIONS

Symbol	Meaning
C.F.A.	Compacted fly ash
C_u	Undrained shear strength
H/B	Ratio between the depth of fly ash 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

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		
ϕ_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*

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

Table 3 Results of physical, standard Proctor and direct shear test for fly ash.

Material Properties	Value	Type of test	standard
G_s	2.78	Specific gravity	*ASTM D854*
$\gamma_{d\,max}$	16.5 kN/m^3	Standard Procter test	*ASTM D698*
$\omega_{opt.}$	24%		
C_u at ω_{opt}.	5kPa	Direct shear test	*ASTM D3080*
ϕ_u at ω_{opt}.	30^o		

Table 4 Results of chemical tests for fly ash.

SO_3 %	1.72
Organic matter %	0.98
$CaCo_3$ %	4
Cl %	0.18
pH	7.14

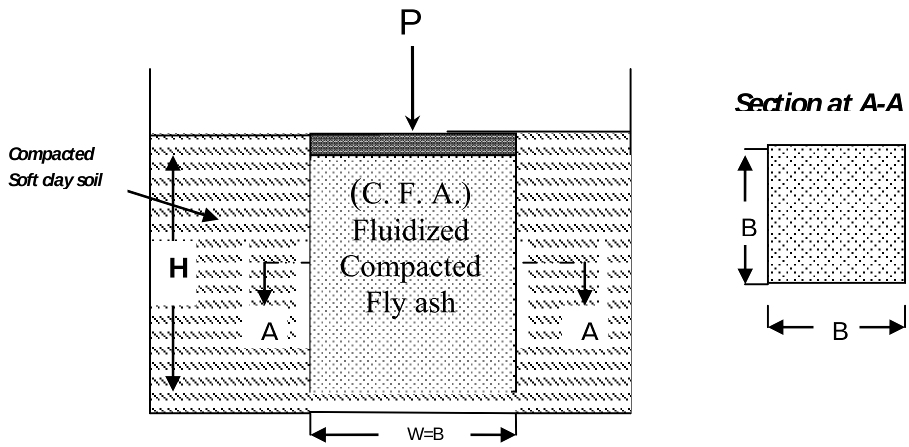

Fig.1 Rectangular footing on **C.F.A.,** note that: width of compacted fly ash column **C.F.A.** =W, width of footing = B, W=B

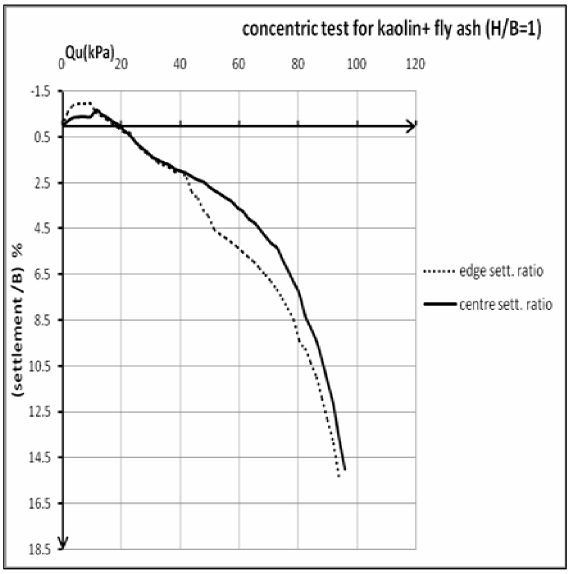

Fig.2 Pressure-settlement ratio curve for kaolin with fly ash (H/B=1), concentric loading

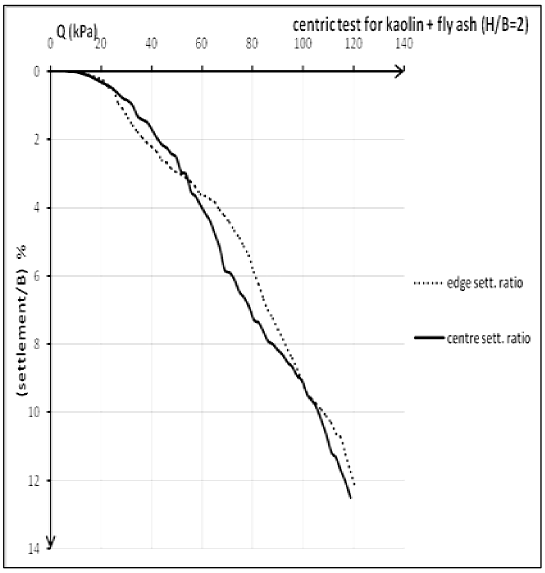

Fig.3 Pressure-settlement ratio curve for kaolin with fly ash (H/B=2), concentric loading

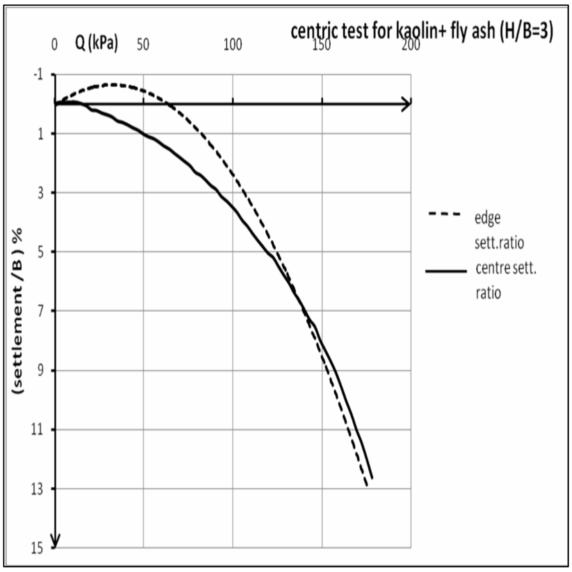

Fig.4 Pressure-settlement ratio curve for kaolin with fly ash (H/B=3), concentric loading

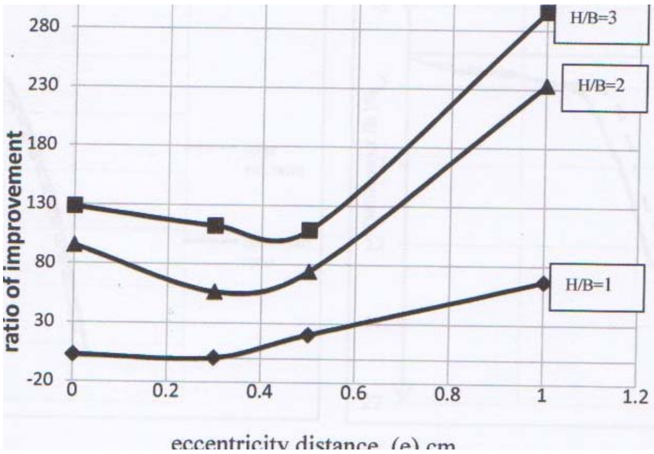

Fig.5 Ratio of improvement and eccentricity relationship at different values of H/B ratio,"kaoline- fly ash"

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

ype of material used	Qu(kPa)	H/B	e(cm)	percent of improvement ratio%	Test no.
kaolin	82	0	0	0	1
kaolin +fly ash	84	1	0	2.4	2
kaolin + fly ash	105	2	0	28	3
kaolin + fly ash	160	3	0	95	4
kaolin	84	0	0.3	0	5
kaolin + fly ash	78	1	0.3	0	6
kaolin + fly ash	74	2	0.3	-	7
kaolin + fly ash	95	3	0.3	13	8
kaolin	57	0	0.5	0	9
kaolin + fly ash	57	1	0.5	-	10
kaolin + fly ash	62	2	0.5	8.8	11
kaolin + fly ash	98	3	0.5	71.9	12
kaolin	24	0	1	0	13
kaolin + fly ash	40	1	1	66.7	14
kaolin + fly ash	71	2	1	195.8	15
kaolin + fly ash	80	3	1	233.3	16

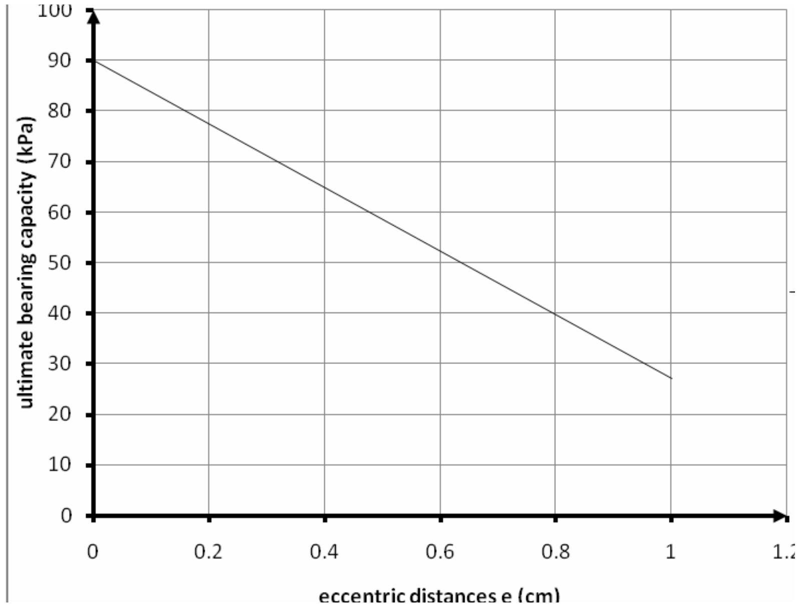

Fig.6 Ultimate bearing capacity vs. eccentric distance relationship**.**

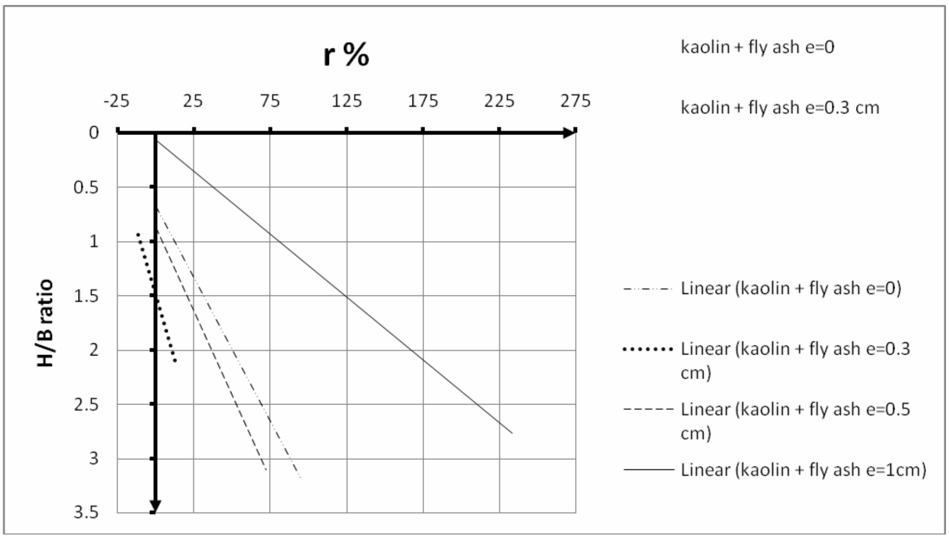

Fig.7 Ratio of improvement and H/B relationship at different values of eccentricity, "kaolin improved by fly ash"

Table 5 Predicted equations for estimating improvement ratio from depth ratio

Type of material and test	**Equations**	**R^2**
Kaolin+ fly ash , e=0	r %= 38(H/B) -25.7	0.82
Kaolin+ fly ash, e=0.05B	r %= 21(H/B) -32	0.16
Kaolin+ fly ash, e=0.85B	r %= 27(H/B) -24	0.693
Kaolin+ fly ash, e=0.167B	r %= 90(H/B) -6	0.96