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Improvement of Soft Clay Using Floating Cement Dust-Lime Columns

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***Abstract*—**The two main criteria that control the design and performance of footings are bearing capacity and settlement of soil. In soft soils, the construction of buildings, storage tanks, warehouse, etc. on weak soils usually involves excessive settlement problems. To solve bearing capacity or reduce settlement problems, soil improvement may be considered by using different techniques, including encased cement dust–lime columns. The proposed research studies the effect of adding floating encased cement dust and lime mix columns to soft clay on the clay-bearing capacity. Four experimental tests were carried out. Columns diameters of 3.0 cm, 4.0 cm, and 5.0 cm and columns length of 60% of the clay layer thickness were used. Numerical model was constructed and verified using commercial finite element package (PLAXIS 2D, V8.5). The verified model was used to study the effect of distributing columns around the footing at different distances. The study showed that the floating cement dust lime columns enhanced the clay-bearing capacity with 262%. The numerical model showed that the columns around the footing have a limit effect on the clay improvement.

***Keywords*—**Bearing capacity, cement dust – lime columns, ground improvement, soft clay.

I. Introduction

THE constructed structures on soft soils face many problems such as large settlement and low bearing capacity. The traditional treatments are very expensive due to raw material prices and the executing cost. To solve these problems, a method that features economy and give an acceptable improvement must be used to enable the government to continue the development process. There are many methods that can be used to improve soft clay properties such as pre-consolidation using prefabricated vertical drains, stone or granular columns [8], grouting with lime and lime silica [9], and trench of cement dust [6]. Columns insertions in soft formation are used widely because of its acceptable improvement of soft soils. The most common columns used are granular column, geosynthetic encased column, concrete pile, lime pile and cement-lime columns. The cement dust - lime column is one of the column types that used to improve the shear strength of the soil and reduce the settlement of the soil. The compressive strength of the soil increased in the presence of cement dust and also the plasticity index of the soil increased [5]. The use of cement dust improves the soils for sub base application [10].

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II. Material Properties

A. Kaolinite (Clay)

Clay was prepared from kaolinite. Experimental tests were performed on clay and the results for some parameters is shown in Table I.

TABLE I
KAOLINIT PROPERTIES [7]

Test type	Property	Value
Atterberg limits	Liquid limit	29.2%
	Plastic limit	18.1%
	Plasticity index	11.1%
Direct shear box	Cohesion, C kg/cm^2	0.07
	Friction angle	1

B. Sand

Sand was used with 66% percentage of column mix component, because the mix is very fine due to the presence of cement dust and lime. Sieve analysis, minimum, and maximum densities were performed as shown in Fig. 1 and Table II.

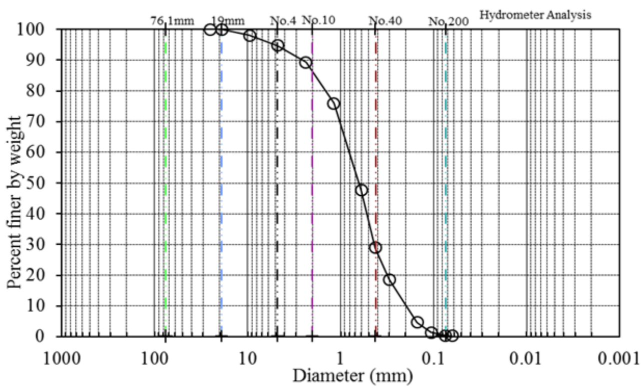

Fig. 1 Grain size distribution

TABLE II
PROPERTIES OF THE SAND USED IN THE MIX

Test type	Property	Value
Relative density	Minimum density (gm/cm^3)	1.57
	Maximum density (gm/cm^3)	1.80

C. Geotextile Material

Non-woven geotextile was used to confine the column. Table III shows the test results.

TABLE III
GEOTEXTILE MATERIAL PROPERTIES

Test	Test Method	Result	Unit
Fabric weight	[1]	438.51	g/m^2
Tensile strength	[2]	5.86	kN/m
Thickness	[3]	2.44	mm
Puncture	[4]	260.24	N

III. PHYSICAL MODEL SETUP

A three-dimensional steel model with dimension (1.4 m * 1.6 m * 0.7 m) was used. The model consists of steel tank stiffened with steel angles as shown in Fig. 2. Pipe network was installed in sand layer at the tank bottom to increase the rate of clay consolidation as shown in Fig. 3.

Fig. 2 Physical model

Fig. 3 Drainage system under clay layer

A. Kaolinite Preparation

The kaolinite material was mixed with water for 15 min. After that, 50 cm thickness of clay was poured in the tank to form the clay layer. The consolidation process began by applying concrete slab and balloon pressure with dimension equal to tank dimension as shown in Fig. 4 to reach shear strength equal 7 kPa. The final thickness of the clay after reaching the required shear strength is equal to 35 cm.

B. Column Formation and Installation

The column mix consists of 30% cement dust, 4% lime, and 66% sand. The column mix was prepared and encased with non-woven geotextile material. The columns were installed in the clay layer by displacement method as shown in Fig. 5.

C. Loading Frame Elements

The loading frame consists of steel support; steel beam rested on the two supports and the loading instrument as explained in Fig. 6. A steel plate with dimension (15 cm*15 cm*2 cm) was used as a loading plate. LVDT was installed to determine the settlement corresponding to each applied load.

Fig. 4 Consolidation Process

Fig. 5 Columns installation

Fig. 6 Loading frame elements

D. Experimental Program

Four tests were carried out as listed in Table IV.

TABLE IV
EXPERIMENTAL TEST PROGRAM

Test No.	Size of the footing	column length (% of clay thickness)	column diameter (D)	spacing
T 0 E		Initial case		
T 1 E		60 % (21 cm)	3.5 cm	
T 2 E	15 cm	60 % (21 cm)	4.0 cm	3D
T 3 E		60 % (21 cm)	5.0 cm	

IV. FINITE ELEMENT IMPLEMENTATION

A plain strain numerical model was constructed by using (PLAXIS 2D, V8.5) to simulate the physical model tests considering elastoplastic behavior of soft clay and columns. 15-noded triangular elements and basic boundary conditions were used to represent the clay and columns as shown in Fig. 7.

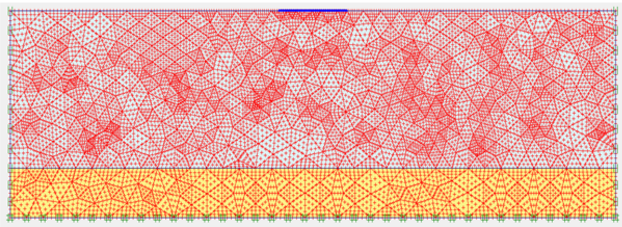

Fig. 7 Finite element mesh

To simulate the columns in two-dimensional model, the three columns were replaced by a ring as shown in Fig. 8. The ring characteristics are:

- The centerline of the ring is the same centerline of the three columns.
- The cross-section area of the three columns is the same ring area.
- The ring side area is equal to the columns side area.
- The ring thickness is calculated by making the ring area equal to the three columns area.

A. Material Parameters

Different constitutive models were used to simulate the field condition:

- Mohr column model for sand filter and cement dust – lime mix as explained in Table V.
- Hardening soil for Kaolinite is explained in Table VI.

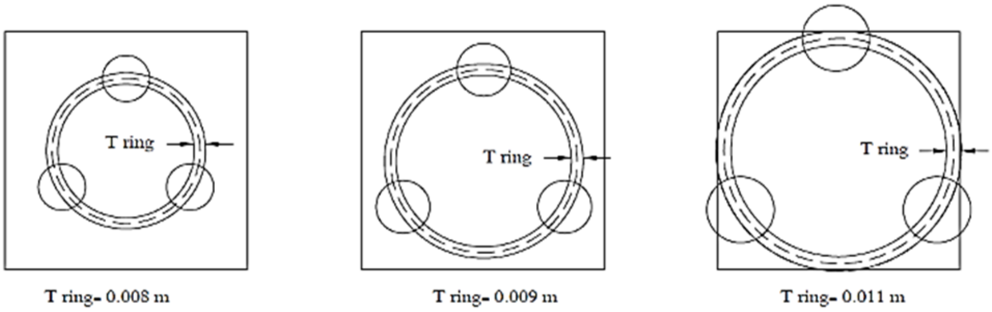

Fig. 8 Ring replaced by the columns and its thickness

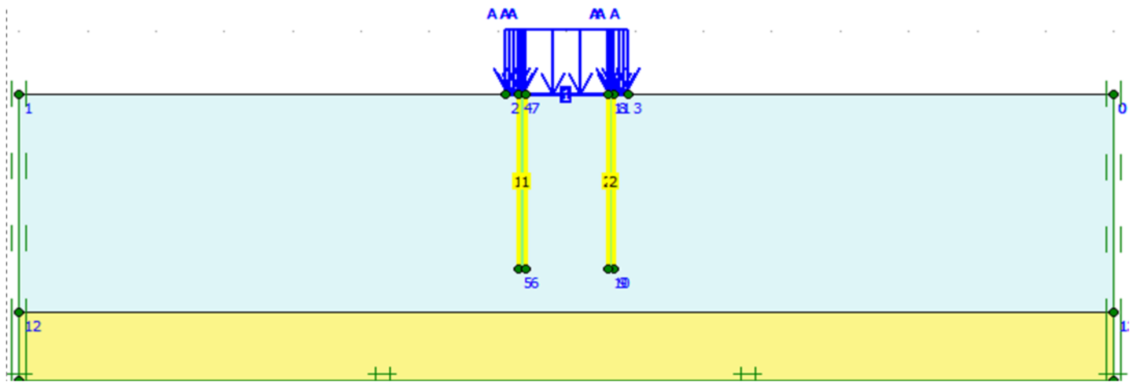

Fig. 9 The Plaxis finite element model

TABLE V
MATERIAL PROPERTIES

Material	E(kPa)	C(kPa)	φ	γ_d(kN/m^3)	γ_{sat}(kN/m^3)
Sand filter	20^4	1	40	17	20
Cement dust – lime - sand mix	10^4	17	37	15	17

TABLE VI
KAOLINITE PARAMETERS

E_{50}(kPa)	C(kPa)	γ_d(kN/m^3)	γ_{sat}(kN/m^3)
700	20	16	21.7

Finally, finite element model is simulated as shown in Fig. 9.

V. RESULTS AND DISCUSSIONS

The results from the laboratory tests showed that cement dust – lime columns (CLC) improved the clay-bearing capacity. At constant length, the increase in CLC's diameters increases the improvement percentage (IP) because the CLC consumes the clay water content in the hydration process for lime and cement dust. The consolidation process resulted from exiting of clay water content leads to enhance clay shear strength and bearing capacity. The geotextile produces a good friction surface between the CLC soil and clay surface area. Fig. 10 shows the experimental results for floating CLCs with different diameters.

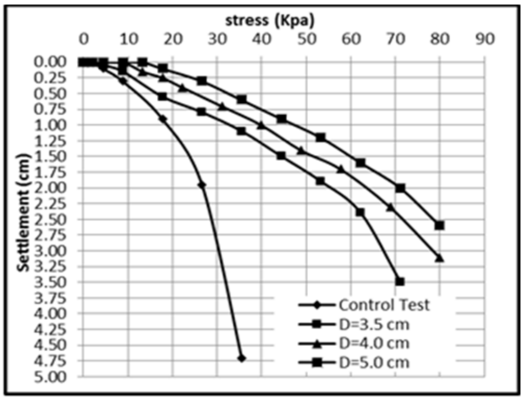

Fig. 10 The effect of using floating CLCs with (60%) length and different diameters

A. Bearing Capacity Improvement

There are many methods for determining the failure stresses. Terzaghi method was considered in this study, where the bearing capacity is corresponding to 10% settlement of the footing width [6] and [11]. The IP is shown in Table VII.

TABLE VII
IMPROVEMENT PERCENTAGE ACCORDING TO TERZAGHI METHOD

Case	Diameter (cm)	Length (cm)	Bearing capacity (kPa)		Improvement (%)
			untreated	treated	
No piles	----	----		----	----
With piles	3.5cm	21	22.89	44.40	194
	4.0 cm	21		51.90	227
	5.0 cm	21		59.98	262

Numerical results were compared with the experimental results to make sure that the model is simulating the actual case. The numerical results showed a good agreement with experimental results as shown in Figs. 11-14.

VI. PARAMETRIC STUDY

A parametric study was carried out using the verified model to study the effect of installing columns around the footing with different distances as shown in Fig. 15.

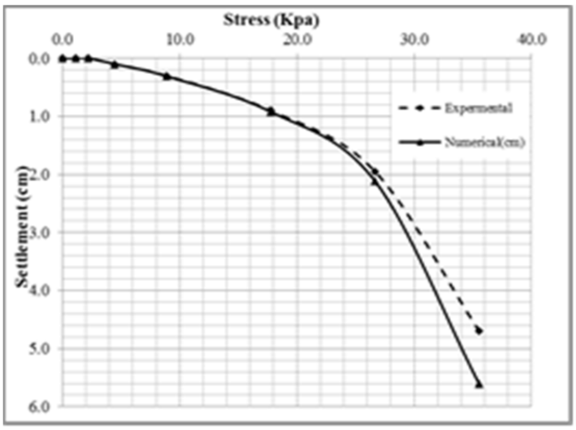

Fig. 11 Untreated case

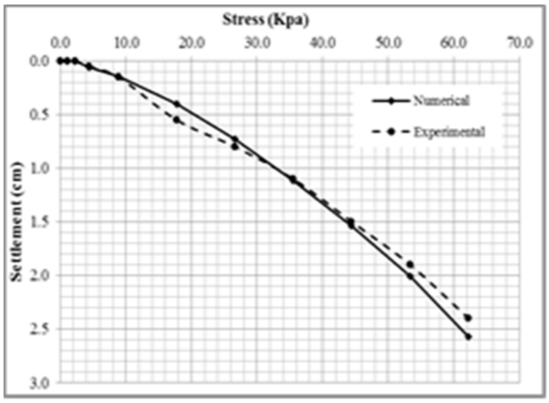

Fig. 12 Clay treated with columns (3.5 cm diameter and 21 cm length)

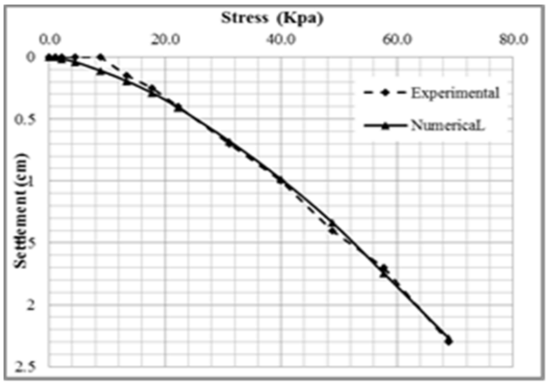

Fig. 13 Clay treated with columns (4.0 cm in diameter and 21 cm length)

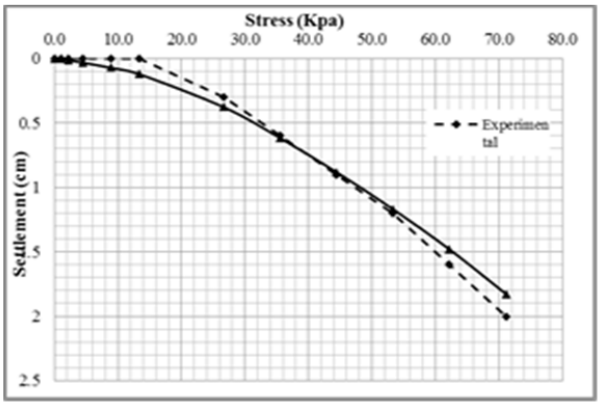

Fig. 14 Clay treated with columns (5.0 cm in diameter and 21cm length)

Finite element model is simulated as shown in Fig. 16. The tests showed that the distance that equals 0.5B from each side of the footing is the most effective distance because the columns in this distance located in the clay active zone so these columns carry the stress distributed in the soil during the loading process. At distance 1.0B, the stress carried by columns decreased because the stress distributed in soil was carried by the nearest columns, so the stress carried by these columns was very small.

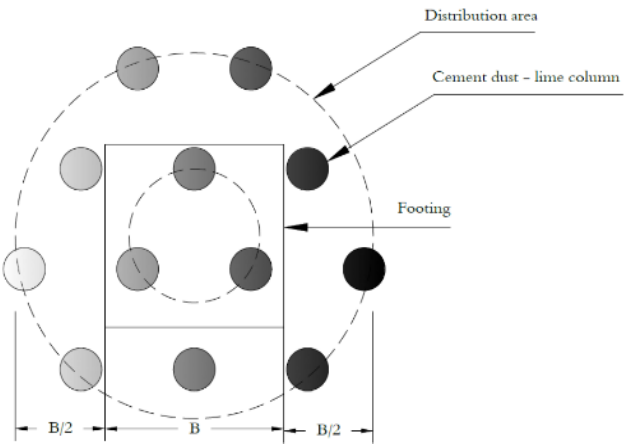

Fig. 15 Distributed columns around the footing

B. *Parametric Study Program*

Table VIII shows the parametric study test program using the verified model.

TABLE VIII
PARAMETRIC STUDY PROGRAM

Test. No	L (cm)	D (cm)	S (cm)	Distribution area
T-ps1	21 cm	3.5	3D	0.5B
T-ps2	21 cm	3.5	3D	1.0B
T-ps3	21 cm	3.5	3D	1.5B
T-ps4	21 cm	3.5	6D	2.0B
T-ps5	21 cm	3.5	6D	2.5B
T-ps6	21 cm	4.0	3D	0.5B
T-ps7	21 cm	4.0	3D	1.0B
T-ps8	21 cm	4.0	3D	1.5B
T-ps9	28 cm	4.0	3D	1.5B
T-ps10	28 cm	4.0	6D	2.0B
T-ps11	28 cm	4.0	6D	2.5B
T-ps12	28 cm	5.0	3D	0.5B
T-ps13	28 cm	5.0	3D	1.0B
T-ps14	28 cm	5.0	3D	1.5B
T-ps15	28 cm	5.0	6D	2.0B
T-ps16	28 cm	5.0	6D	2.5B

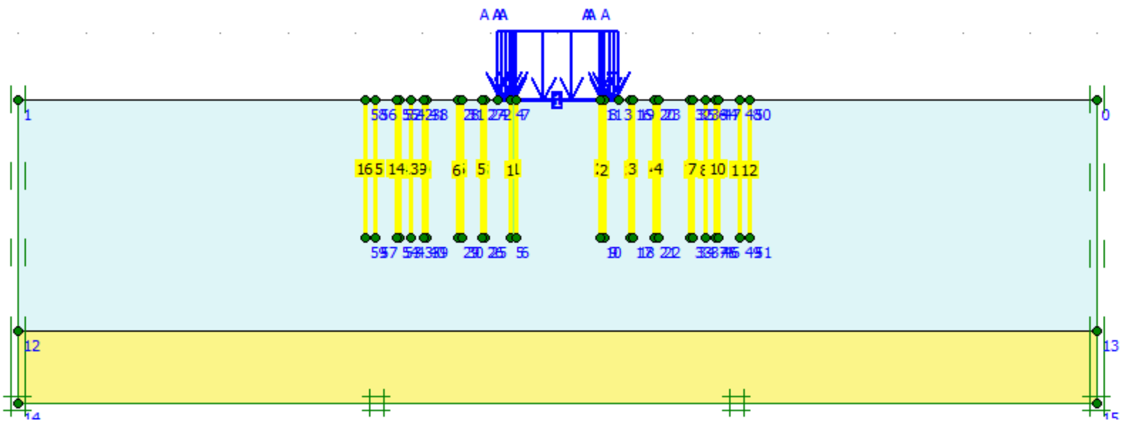

Fig. 16 Simulating columns with a diameter of 3.5 cm

VII. EFFECT OF INCREASING THE DIAMETER

A. *At Diameter=3.5cm & Length = 21 cm*

The tests showed that the external columns distributed around the footing at different distances have a slight effect on the clay improvement because the columns length and diameter were very small, so the column stiffness is very small to carry stress. Fig. 17 shows the external column results.

B. *At Diameter 4.0 cm & Length = 21 cm*

By increasing the diameter of the column, the columns stiffness increased. The columns under the footing became stiffer, so most of the stress is carried by the columns under the footing. The external columns, in this case, are not totally effective because some stress will be transferred to them. So, the clay-bearing capacity is improved as shown in Fig. 18.

C. *At Diameter 5.0 cm & Length= 21 cm*

The external columns were totally not effective because the columns became very stiff due to increase in length and diameter as shown in Fig. 19.

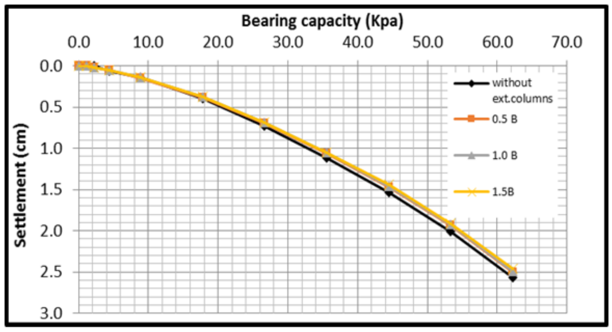

Fig. 17 Results of columns with diameter 3.5 cm and length = 21 cm

VIII. CONCLUSION

The following are the general conclusions of this study:

1. The cement dust – lime columns increase the soil bearing capacity with percentage 262% and reduced the clay settlement.
2. The effective distance to distribute columns around footing is 0.5B, where B is the footing width.
3. The clay shear strength increased from 7 kPa to 20 kPa

after treatment with CLCs.

4. By increasing the column diameter, the external columns become not effective.

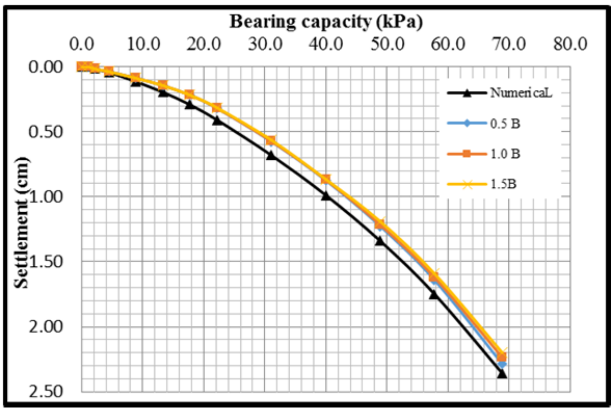

Fig. 18 Results of columns with diameter 4.0 cm and length = 21 cm

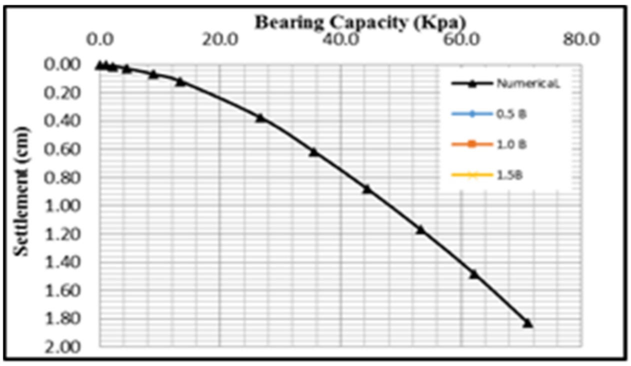

Fig. 19 Results of columns with diameter 5.0 cm and length 60%

REFERENCES

[1] ASTM D-5261, Standard Test Method for Measuring Mass per Unit Area of Geotextiles

[2] ASTM D-4595, Standard Test Method for Tensile Properties of Geotextiles by the Wide-Width Strip Method1

[3] ASTM D-5199, Standard Test Method for Measuring the Nominal Thickness of Geosynthetic.

[4] ASTM D-4833, Standard Test Method for Index Puncture Resistance of Geomembranes and Related Products.

[5] Azad, S. (2000). Influence of soil type on stabilization with cement kiln dust, Construction and Building Materials, Vol. 3.

[6] Dr. Mosa J. Aziz Al-Mosawe, Dr. Bushra S. Albusoda, Azhar S. Yaseen ,2009," Bearing Capacity of Shallow Footing On Soft Clay Improved By Compacted Cement Dust", Journal of Engineering Volume 15.

[7] Egyptian code for soil mechanics and design and executing the foundation 2009, part 2

[8] Hughes, J. M. O. and Withers, N. J., 1974, "Reinforcing of Soft Cohesive Soils with *Stone* Columns," Ground Eng., Vol. 7(3), pp. 42–49

[9] Mohammed Y. Fattah, A'amal A. Al-Saidi, and Maher M. Jaber, 2015," Improvement of bearing capacity of footing on soft clay grouted with lime-silica fume mix", Geomechanics and Engineering, Vol. 8, No. 1.

[10] McCoy, W.J. and Kriner. R.W. (1971). "Use of Waste Kiln Dust for Soil Consolidation". Lehigh Portland Cement Co., Allentown, Pennsylvania, U.S.A.

[11] Zakariya, W. A. S., 2001, "Soil Improvement Using Stabilized and Non-Stabilized Stone Columns with Different Reinforcement Configuration," Ph.D. thesis, Building and Construction Engineering Department, University of Technology, Iraq, p. 142.