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Consolidation of Soft Clay Using Slag- Cement Dust Columns

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Abstract : Soft clay is a problematic soil due to its low bearing capacity and high settlement. To treat such soil, many techniques were developed, such as a replacement method with sand bed, stone columns, sand columns, vertical sand drains…. etc. The main objective of this study is to investigate the effect of the introduction of slag-cement dust columns to soft clay on the consolidation parameters such as coefficient of consolidation, compression index, and compressibility index. Three consolidation tests were carried out on three soft clay samples. The first sample was soft clay without treatment. The second sample was soft clay treated with one slag-cement dust column, and the third sample was treated with three slag-cement dust columns. All Samples were tested in a Modified Consolidation Apparatus. A relationship between void ratio and stress was deduced. The tests showed that the columns increased the clay consolidation rate and decreased the compression index, where the columns absorbed the clay water content. The consolidation coefficient values for the treated clay soil proved that Han's model applies to clay treated with slag-cement dust columns (SCCs).

KEYWORDS: Modified Consolidation Test, Slag, cement dust, Consolidation Parameters

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1. INTRODUCTION

Columns are one of the techniques implemented to improve the soft clay shear strength, increase the clay-bearing capacity and decrease the total settlement. thus, the areas where soft clay is the main soil formation can be invested. Studies have been carried out to investigate the effect of using columns to improve soft clay. (Deb et al., 2011) studied the effect of the placement of reinforced sand bed above stone columns on the clay bearing capacity and settlement. They proved that the reinforced sand bed above the stone columns increased the clay-bearing capacity. (Han & Ye, 2001) developed an empirical equation to estimate the clay coefficient of consolidation after treatment with stone columns, and the developed equation proved that the columns can accelerate the clay consolidation. (Ghazavi & Nazari Afshar, 2013; Ghazavi & Nazari, 2013; Ouyang et al., 2015) conducted laboratory tests to analyze soft clay treated with one or a group of encased stone columns. Field observations showed that stone columns could also accelerate the rate of consolidation of soft. Measurement of Field pore water pressure under an embankment indicated that a homogenous clay stratum outside a stone column treated area completed 25% primary consolidation when the stone column area had reached 100% primary consolidation (Munfakh et al., 1984). (Han & Ye, 2001) reported that, the settlement rate of two similar buildings, one on an unreinforced foundation and the other on a stone column reinforced foundation in the same site. The settlement reached 66 and 95%, respectively, over the same period of 480 days. The columns can accelerate the clay consolidation rate by creating a drainage path along the column's depths; therefore, the pore water pressure dissipates quickly. Also, columns transfer part of applied loads to the deeper soil—the columns act as a friction pile. (Fattah et al., 2013) evaluated the stress concentration ratio by conducting an experimental model using stone columns mixed with some additives in soft soil. The additives were a percentage of sand with stone and a percentage of cement with stone. The shear strength of the clay is varied between three values 6,9,12 kPa. The number of columns used in the research is varied between one to four columns. it was concluded that Stress concentration (the ratio between the stress transfer to the column to the stress transfer to the clay) value increased with the increase of the shear strength of the clay, The stress concentration value for the fully penetrating column is higher than the floating column because the second one depends on the skin friction only, The sand additives to the crushed stone recorded a marginal effect on the stress concentration value in the clay with a shear strength of 6 kPa, but the effect was weak with the clay with a shear strength of 12 kPa. (Belal et al., 2019) studies the effect of using floating and end-bearing columns from cement dust and lime on the clay-bearing capacity. The experimental model was implemented and defensed by FEM. The tests showed that the floating columns behave better than the end-bearing column. The increase in column diameter leads to improvement because the stress applied is distributed in a large area. At constant diameter, the increase contact area between soil and columns increases as the column behaves as a friction pile. The end bearing had a limited effect on clay improvement because the column had a low compressive strength after seven days, so the column (in end-bearing condition) failed due to the applied stress. (Ali, 2019) studied the effect of using the encased sand columns on very soft clay behavior. The results showed that the column with length L/H=0.8 has the most improvement percentage and the End–bearing columns had a limited effect on clay improvement. (Suvvari et al., 2015) implemented an experimental model to study the effect of installing a reinforced slag column in soft clay on the clay-bearing capacity and indicating the maximum bulging value along the column. The slag used in this study was obtained from the smelting process in the ferro-alloy industry. Major constituents of Silica-Manganese slag were SiO_2 and CaO for about 24% and 45%, in-depth leads to an improvement percentage because the respectively. The results showed that the bearing capacity improved after installing the reinforced slag column according to the load-settlement curve. The ultimate load-carrying capacity of the plain clay bed is 34kg, and the corresponding settlement is 7.5mm. The maximum load-carrying capacity with the stone column is 43kg. The column inclusion increased the load-carrying capacity by 26% for clay beds alone. The settlement at the ultimate load has also been reduced to 7.1 mm.

The proposed study objective is to conduct laboratory tests for clay treated with one and three slag – cement dust columns (SCCs) in a modified consolidation apparatus to calculate the consolidation rate (Cv) and compression index (Cc) for the different cases. The results will be compared with Han's empirical equation for predicting the consolidation rate of treated soft clay.

2. EXPERIMENTAL STUDY

In this study, modified consolidation apparatus was used. It consists of a steel square base with dimensions (160 mm * 160 mm * 30 mm) and a circular ring (110 mm) diameter (Figure 1). Modified consolidation apparatus is slightly different from conventional consolidation test apparatus as the circular steel ring is larger to increase the internal model volume. Soft clay was brought from Mahmoudia corridor – Alexandria. Soft clay was placed inside the steel ring and wrapped with a very thin plastic bag to ensure that the water pass only towards the SC columns (Figure 2) . The SC columns with 22 mm diameter and 30 mm height were installed in the middle of the Sample (Figure 3) (Figure 4) The column consists 83.0 % Slag and 17 % cement dust. The soft clay treated with SC columns was wrapped with the plastic bag (Figure 5) and the loading group was installed above the clay sample (Figure 6) . The loading system is the same as conventional one. It consists of a thin circular plate placed above the sample to distribute the load over the complete sample area. It also includes a dial gauge to record the sample settlement and loading arm to apply magnified load on the sample (Figure 7) .

Fig 1: Sample Ring

Fig 2: Prepared Sample

Fig 3: Soft Clay Treated with One SC column

Fig 4: Soft Clay Treated with Three SC Columns

Fig 5: Sample after Wrapping with Thin Plastic Bag

Fig 6: Sample under Loading

Fig 7: Loading Frame and Dial Gauge

Table 1 shows the test program for the current study. Different stresses were applied on the samples in which every stress was applied for one day. A relationship between stresses applied and the void ratio was figured out.

Table 1: Test Program

Test No.	Column Length (% for the clay thickness)	Column Diameter (mm)	Column Height (mm)	Spacing (mm)	No. of column
T 0 E	Control Test				
T 1 E	100%	22.0	30.0	-----	1.0
T 2 E	100%	22.0	30.0	30	3.0

3. RESULTS AND DISCUSSION

Figure 8 shows the consolidation test results for the clay without treatment. Figure 9& Figure 10 show the consolidation test results for clay treated with one column and clay treated with three columns, respectively

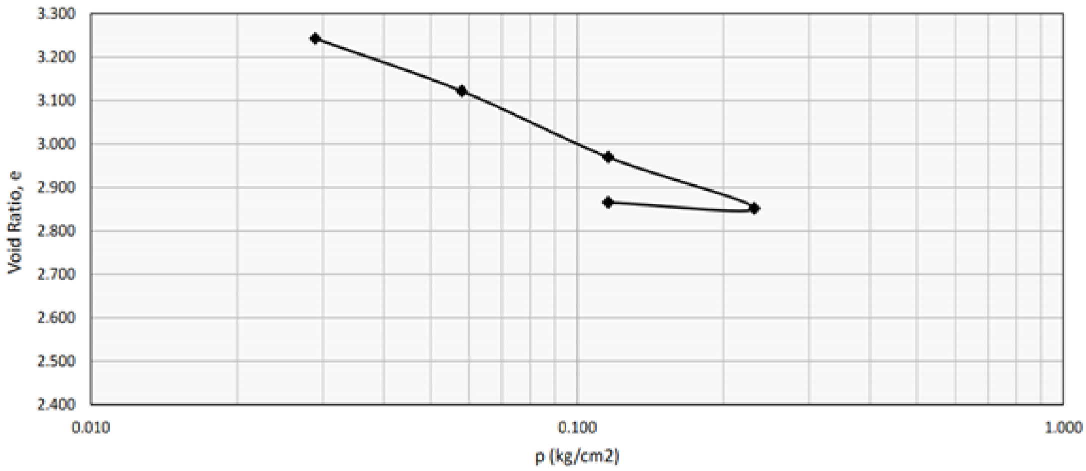

Fig 8: Consolidation test Results for Clay With no Treatment

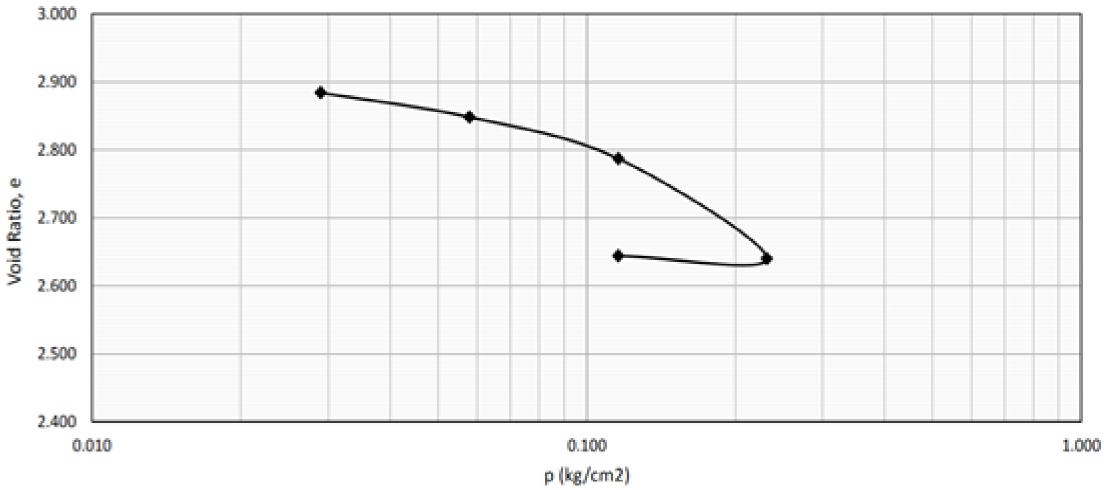

Fig 9: Consolidation Test Results for Clay Treated with One SC Column

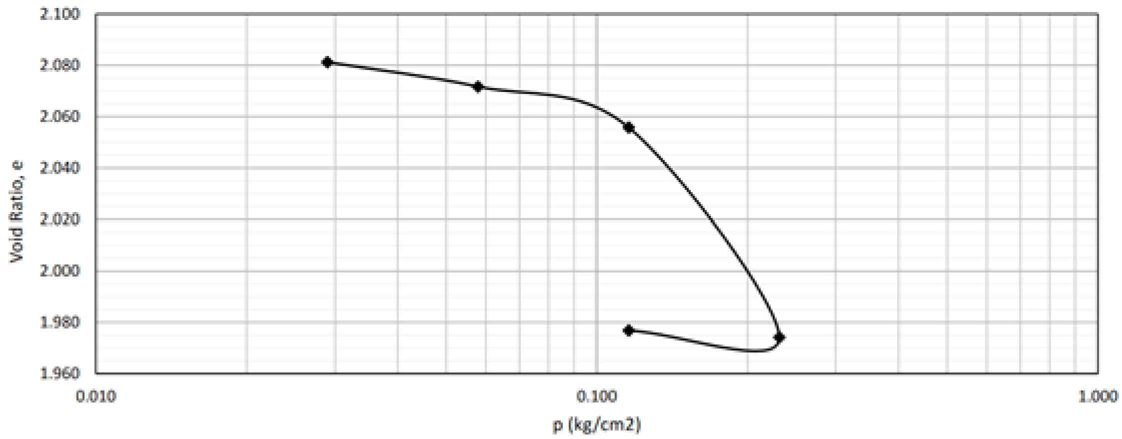

Fig 10: Consolidation Test Results for Clay Treated with Three SC Column

Table 2: Consolidation Rate and Compression Index Results For all Tests.

Pressure (Kg/cm^2) Cv (cm^2/min)	0.25	0.5	1	2	Cc (compression Index)
Clay	1.32	0.848	0.477	0.305	0.448
Clay + 1Column	2.3556	1.576	0.712	0.415	0.251
Clay+3Columns	2.3556	1.908	0.954	0.58	0.140

The tests results showed that, the SC column increased the clay consolidation rate by 55%, as the SC columns shortened the water path. SC column could absorb the water content from the surrounding soil. The compression index (Cc) decreased by 44% for clay treated with one SC column and 69% for clay treated with three columns. The columns carried a part of the load applied on the treated clay sample, so the clay's compressibility decreased. The column became stiffer because of cement dust that binds the mixture together. The columns transferred apart from the loads applied to the deeper plate (end-bearing columns). Figure 11 shows the comparison between all tests results. The last figure showed that the columns significantly affect the clay compression index.

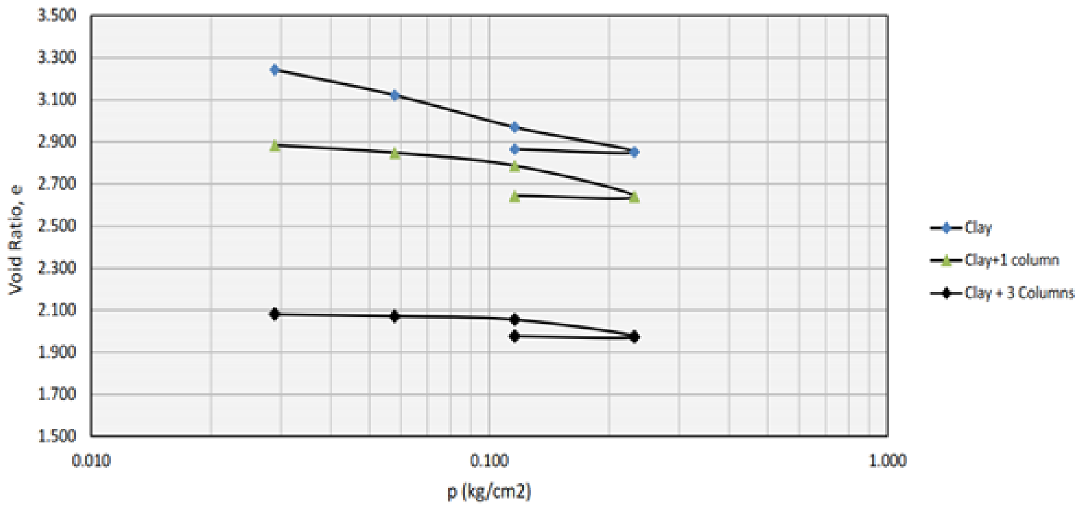

Fig 11: Consolidation Test Results for All Tests

The results showed that the first applied stress has the same consolidation rate for the clay treated with one column and three columns because this stress is the initial one, and the columns do not entirely extract the clay water content. The consolidation rate for clay treated with three columns became larger than clay treated with one column by increasing the stress. The increase in columns number led to more paths for water to be extracted faster. The consolidation rate for clay treated with one column and clay treated with three columns in the second stage were 46% & 56%, respectively. In the third stage (at stress 1 kg/cm2), the treatment soils' consolidation rate was higher than untreated soil because the column still extracted the clay water content. The consolidation rate for clay treated with one column and clay treated with three columns in the second stage were 33% & 50%, respectively. In the third stage, it is noticeable that the consolidation rate for the treated soil became lower than the previous stage because the column extracted much water. At the last stage, the treatment clay's consolidation rate became lower than the consolidation rate in the previous step. The columns extracted more and more clay water content, and the column extraction efficiency decreased. The results showed that the compression index (Cc) decreases because the columns carry part of stress applied on clay and transfer it to deeper soil; therefore, the remaining stress on clay is low and consequently, the compression index decreased.

4. REVIEW OF JIE HAN EQUATION AND CHARTS

(Han & Ye, 2001) developed a simplified method for computing the consolidation rate to account for a drained modular ratio between the stone column and the soil or a stress concentration ratio. The solution supports earlier findings by a numerical study (Balaam and Booker 1981) as the consolidation rate can be accelerated by increasing the modular ratio and reducing the diameter ratio (influence diameter/column diameter). The Terzaghi 1D consolidation solution and the (Barron, 1948) solution for drain wells in fine-grained soil are exceptional cases of the simplified solutions developed in this paper that underestimate the consolidation rate of stone column reinforced foundations. The new solutions demonstrated the stress transfer and the dissipation of excess pore water pressures due to drainage and vertical stress reduction in consolidation. Comparing the results from the simplified method and a numerical study shows reasonable agreement, especially when the steady-stress concentration ratio is within a typical range (2–6). The discrepancies in results for these two methods are discussed, mainly resulting from different assumptions adopted in one or 3D deformation. A design example, which used the design charts

developed in this paper, demonstrates the difference in prediction for the consolidation rate from the classical solutions. The classical solutions require a much longer time to achieve the same rate of consolidation rather than the new method.

In this study, a simplified method produced by (Han & Ye, 2001) will be used to evaluate its applicability for this kind of column. The equations used for determining the consolidation rate for treated clay:

$$\boldsymbol{Cv}\,(\boldsymbol{modified}) = \boldsymbol{cv}\,\left(\mathbf{1} + \boldsymbol{ns}\,\frac{\mathbf{1}}{\boldsymbol{N}^{\mathbf{2}}-\mathbf{1}}\right) \qquad (1)$$

$$\boldsymbol{ns} = \boldsymbol{x} * \frac{\boldsymbol{Ec}}{\boldsymbol{ES}} \qquad (2)$$

$$\boldsymbol{x} = \frac{(\mathbf{1}+\boldsymbol{us})(\mathbf{1}-\mathbf{2}\boldsymbol{us})(\mathbf{1}-\boldsymbol{uc})}{(\mathbf{1}+\boldsymbol{uc})(\mathbf{1}-\mathbf{2}\boldsymbol{uc})(\mathbf{1}-\boldsymbol{us})} \qquad (3)$$

$$N = \frac{\boldsymbol{de}}{\boldsymbol{D}} \qquad (4)$$

$$\boldsymbol{de} = \mathbf{1.13} * \boldsymbol{S} \qquad (5)$$

Where: N = diameter Ratio, ns =steady stress concentration ratio, x= Poisson ratio factor, Ec = young's modulus for column, Es= young's modulus for soil, νs= Poisson ratio for soil, νc = Poisson ratio for soil, de= diameter ratio, S = spacing

The input data for the soil and columns used in this study are listed in Table 3 .

Table 3: Input data for clay and columns

Column diameter (cm)	2.2
Es (kPa)	862.5
Ec (kPa)	3000
ν**s**	0.4
ν**c**	0.25
S (spacing between columns) (cm)	3.0

After using the equation mentioned above, the consolidation rate for all tests is shown in the Table 4.

Table 4: Consolidation rate for all test

Pressure (Kg/cm^2) Cv (cm^2/min)	**0.25**	**0.5**	**1**	**2**	**Cc (compression Index)**
Clay	1.32	0.848	0.477	0.305	0.448
Clay+3Columns	2.3556	1.908	0.954	0.58	0.140
Hans's Equation	**2.4**	**1.916**	**1.08**	**0.691**	**-------**

The results showed that Han's equation predicted values are fairly in agreement with laboratory test results and can be applied for this kind of column.

5. Conclusion

Depending on the Experimental & Laboratory tests performed, it can be concluded that:

- SC columns increase the clay consolidation rate by creating more paths for extracting water from the soil. In addition, the slag can absorb moisture from the surrounding soil.
- SC columns decrease the clay compression index as the column carries a part of the stress applied on the clay and transfers it to the deeper soil; therefore, the remaining pressure on clay is low, leading to a decrease in the clay compression index.
- Han Simplified method can be applied for clay treated with SC columns.

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