MODELLING OF BEHAVIOUR OF THE CLAY SOIL EMBANKMENT REINFORCED BY STONE COLUMN ENCASED WITH GEOGRID UNDER STATIC LOAD

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Abstract: *embankment seated on soft clay may undergo large displacements both vertically and horizontally. Several ground improvement techniques have been adopted to mitigate the displacements. Stone columns provide an influential [1] improvement process for soft soils under light structures such as road embankments or rail. In order to avoid dispersion of the stones into the clay and to improve the stone columns as reinforcing elements, geogrids are used in this study as an encasement of the stone columns. In this study analysis of an embankment resting on encased stone columns ESC is investigated using finite element program "Plaxis 3D 2013". Examples of model prediction and accuracy of finite element formulation were given. Then the transient analysis of three-dimensional embankment problem supported on geogrid reinforced stone columns has been carried out taking in to consideration the influence of some parameters on the long-term behavior of the system, such as stone columns diameter (d).*
Keywords: *clay soil, stone column, embankment, geogrid, soil improvement.*

ПОВЕДЕНИЕ ГЛИНИСТОЙ ПОЧВЫ, УСИЛЕННОЙ КАМЕННОЙ КОЛОНКОЙ, ПОКРЫТОЙ ГЕОРЕШЕТКОЙ, ПОД СТАТИЧЕСКОЙ НАГРУЗКОЙ

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Аннотация: *набережные на мягкой глине могут подвергаться большим смещениям как по вертикали, так и по горизонтали. Для уменьшения смещений было принято несколько методов [1]. Каменные колонны имеют значительное преимущество в улучшении мягких почв под легкими конструкциями, такими как дорожные насыпи или рельсы. Чтобы избежать рассеивания камней в глину и усилить каменные колонны, в качестве усиливающих элементов в этом исследовании используются георешетки как облицовка каменных колонн. В данной работе насыпь на каменных колоннах изучается с использованием программы «Plaxis 3D 2013». Приведены примеры предсказания поведения модели и определена точность метода конечных элементов. Далее был проведен переходный анализ задачи трехмерной насыпи на колоннах с усиленной каменной колонной из георешетки с учетом влияния некоторых параметров на долговременное поведение системы, таких как диаметр колонн (d).*
Ключевое слово: *глина, каменная колонна, насыпь, георешетки, улучшение почвы.*

Introduction

Because of the extreme increasing developments in occupied areas in the past 40 years, a number of ports, dams, industries, and other infrastructure facilities are being built. The construction on natural soft soil is considered a high risk and makes major problems to geotechnical engineers when constructing large embankment on it, because of its low shear strength and high compressibility.

In Iraq, there are more than 1400 km of new railway networks which are expected to be constructed in the near future, in addition to the full rehabilitation of the existing network [5]. About 60% of the new network is located in the middle and southern parts of Iraq where most of the ground is basically sedimentary, soft to very soft cohesive soils especially in areas close to the marshes [3] and nowadays the new railway networks is in constructing progress at the southern part of Iraq.

A lot of soil improvement [2] methods have been used to deal with soft soil problems. The improvement methods of the soft soil include soil replacement, sand drains, vacuum pressure, preloading, dynamic compaction, lime stabilization, geosynthetic reinforcement and stone or gravel columns [6].

The stone columns have stiffness and higher drainage ability than sand The stone columns have stiffness and higher drainage ability than sand drains; therefore, ground [7] reinforcement by stone columns solves the soft soil's problems by providing advantage of reducing settlement and 2

Accelerated consolidation process [4] another feature of this method is the simplicity of its construction. The use of [6] stone columns as a method of soft soil improvement has been successfully implemented around the world. The stone column technique was developed in Germany about 60 years ago.

1 Finite Element Model Verification

The verification of PLAXIS 3D for piled embankment problem was performed by comparing with the experimental work of **Hassan (2013)**. The problem was re-analyzed using PLAXIS 3D 2013. The same parameters employed by **Hassan (2013)** were re-used in the comparative analysis and in the parametric study of this thesis as shown in Table (1).

2. Model test procedure

The model tests were carried out on natural soil and soil improved with ordinary stone columns (OSC) and encased stone columns (ESC). A footing (250 mm×600 mm) in dimensions was placed in position on the surface of the embankment model so that the center of the footing coincides with the center of the load cell and hydraulic jack (Figure 3.3). One dial gauge was fixed in the center of footing to measure the settlements of plate. Loads were then applied through a hydraulic jack in the form of load increments and measured by the load cell and recorded by load readout. During each load increment, the readings of the dial gauges were recorded. The dial gauge readings were recorded at the end of the period of each load increment. Each load increment was left for (5 minutes) or till the rate of settlement became constant.The model dimensions are 1500 mm in length, 800 mm in width and 1000 mm in depth (Figure 3.3). Three embankment heights of; 200 mm, 250mm and 300 mm were tested for untreated embankment and reinforced by ordinary stone columns (OSC) and encased stone columns (ESC), 600 mm the base length of embankment and 300 mm the top of it, the stone column was 70 mm in diameter d and 350 mm in length L, spacing between stone columns S was taken equal to 2.5d with L=5d. The embankment was resting on soil with undrained shear strength ≈ 10 kPa.

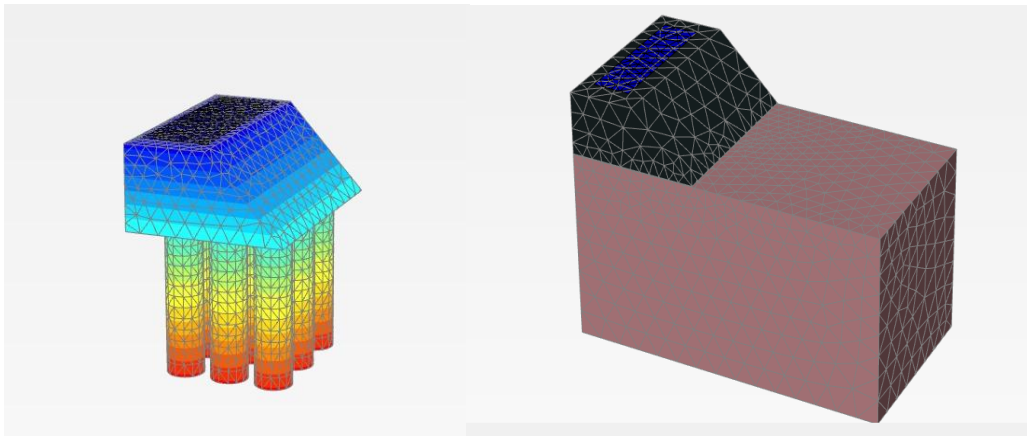
3. Numerical modeling

Shows the three-dimensional finite element modeling of piled embankment system **of Hassan (2013)** by PLAXIS 3D 2013. The numerical modeling consisted of four steps, the first step was initial geostatic equilibrium, the second step was installation of stone columns as ''wished-in-place pile'', the third step was modeling the embankment layers, the layers were 5, each layer was 1m in height, the last step was modeling surface loading on the footing at the top of embankment, the loading was (5, 10, 15, 20, 25, 30 and 35) kPa. In case of modeling (ESC), modeling geogrid encasement for the stone columns and interface element phase was added. Plastic calculation type was used in all phases. Figure 4 shows the finite element mesh which consists of 15-node isoparametric elements.

The results of the bearing pressure versus surface settlement of untreated and treated embankments with different heights resting on soft soil are presented in Figures below It can be noticed from these figures that there is a good agreement with **Hassan (2013)** experimental work and PLAXIS 3D 2013 results.

4. ***Boundary conditions***

In the finite element code, the same model is created as that constructed for the group column plate load test in the field. The depth and width of the model and embankment are selected as sufficient so that it acquires real behaviour of the model. Standard boundary option is selected in the program. This boundary option models the top surface to be free of movement into all directions, the 'embankment top surface' is free in all directions also. When considering the model boundary in yz-plane, displacements in the x directions are limited to zero where displacements in the y and z directions are free. All boundaries are modelled in the same manner. The bottom boundary is fixed in all directions. It is of important that a suitable mesh size is selected that it is fine enough to capture the real behaviour of the model where therewithal the analysis time does not become unreasonable. Due to that reason the global mesh coarseness is selected in the medium range, in addition, the software automatically refines the critical areas in the model. The created geometry of the model and the generated mesh used in analyses are presented in Figures below (a) and (b), respectively.



(a) *(b)*

Fig. 1 (a) Input geometry of the analyzed model in PLAXIS 3D (b) Generated mesh

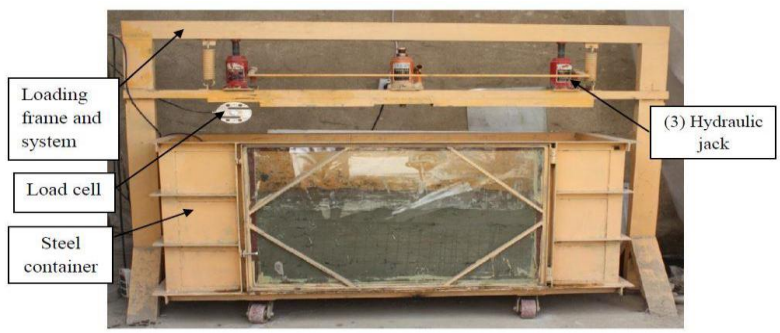


Fig. 2. Experimental test container and loading system (after Hassan, 2013)

Table 1. Material parameters for the numerical analyses (After Hassan2013)

Propeties	**Soft clay**	**Embankment fill**	**Stone column**
Unsaturated unit weight ,γunsat (kN/m3)	13.24	21.83	14.4
Saturated unit weight, γsat (kN/m3)	18.85	24.22	15.7
Material model	Hardening soil	Hardening soil	Mohr-coulomb
Drainage type	Undrained (B)	Drained	Draind
E(kpa)	-	-	150000
E50 ref (kPa)	600	10000	-
Eoed ref (kPa)	1425	10000	-
Eur ref (kPa)	1800	30000	-
Power (m)	1	1	-
Cohesion ,Cu (kPa)	10	1	1
Friction angle, Øu (deg)	-	40	41.5
Geosynthetic stiffness, J (kN/m)	-	-	68

Fig. 3. Pattern of stone columns at s=2.5d

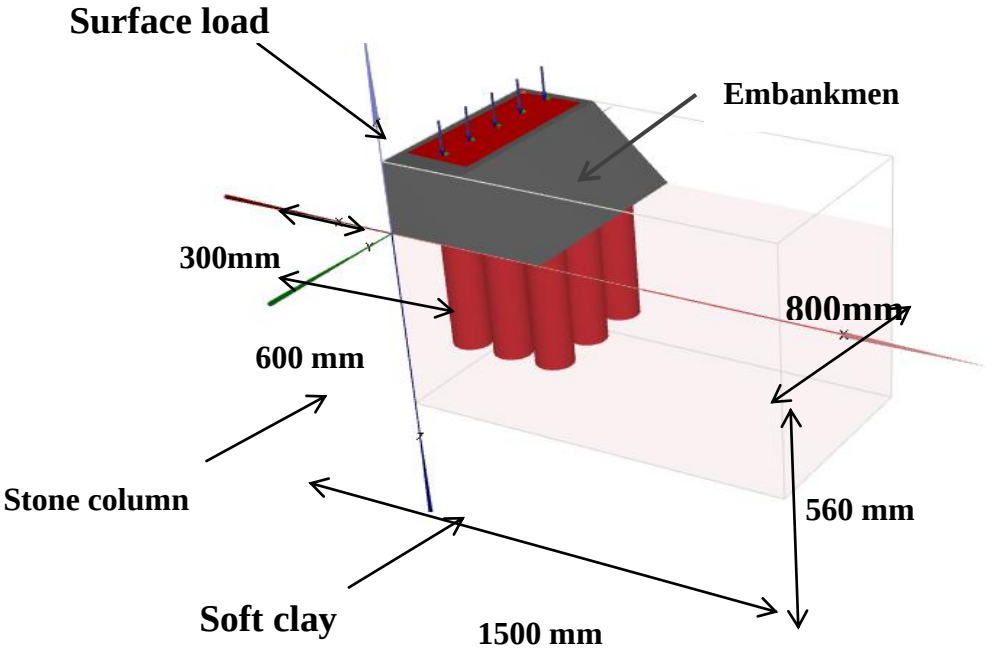


Fig. 4. Three-Dimensional finite element modeling of piled embankment system(L/d=8)

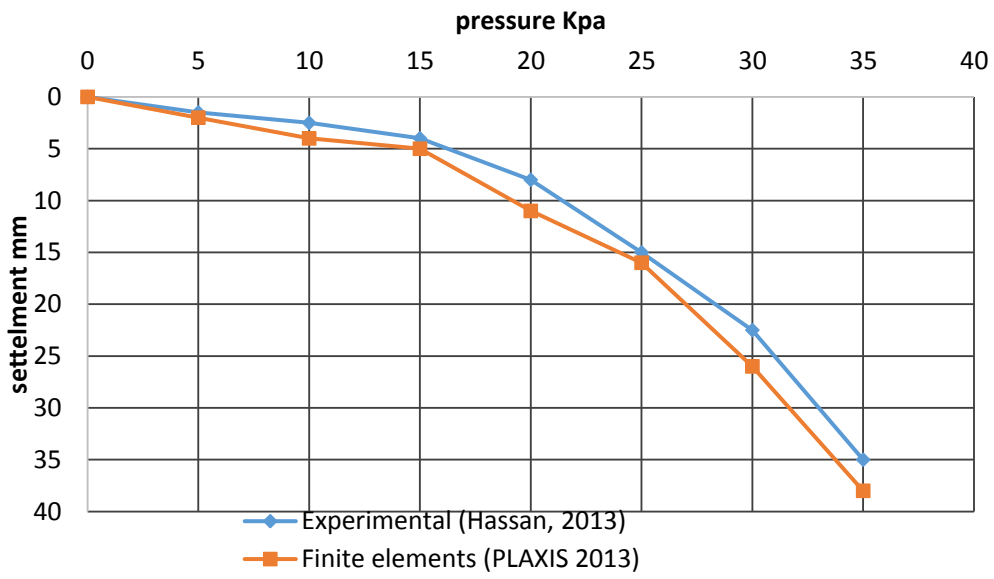


Fig. 5. Results of bearing pressure versus surface settlement relationship of embankment model 200 mm high resting on soft soil treated with ordinary stone column at (s=2.5d)(L/d=8)

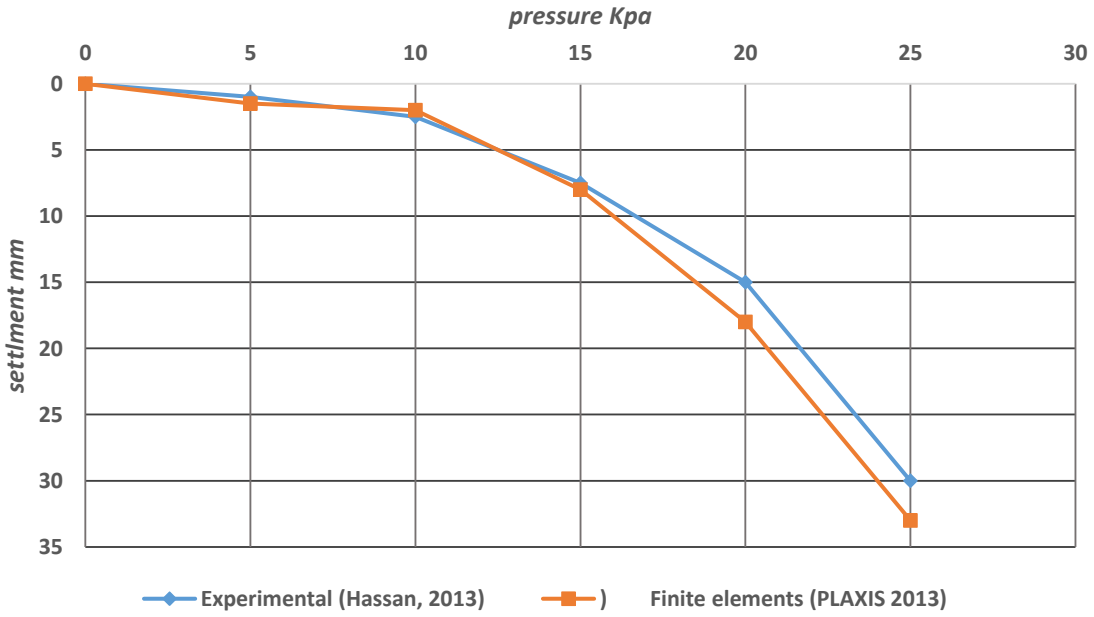


Fig. 6. Results of bearing pressure versus surface settlement relationship of embankment model 200 mm high resting on soft soil treated with ordinary stone column at (s=2.5d)(L/d=5)

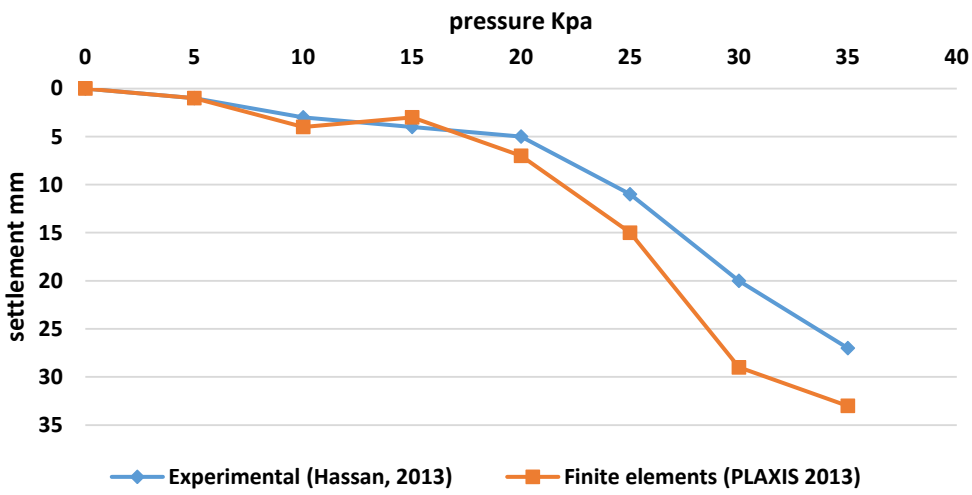


Fig. 7. Results of bearing pressure versus surface settlement relationship of embankment model 200 mm high resting on soft soil treated with encased stone column at (s=2.5d)(L/d=8)

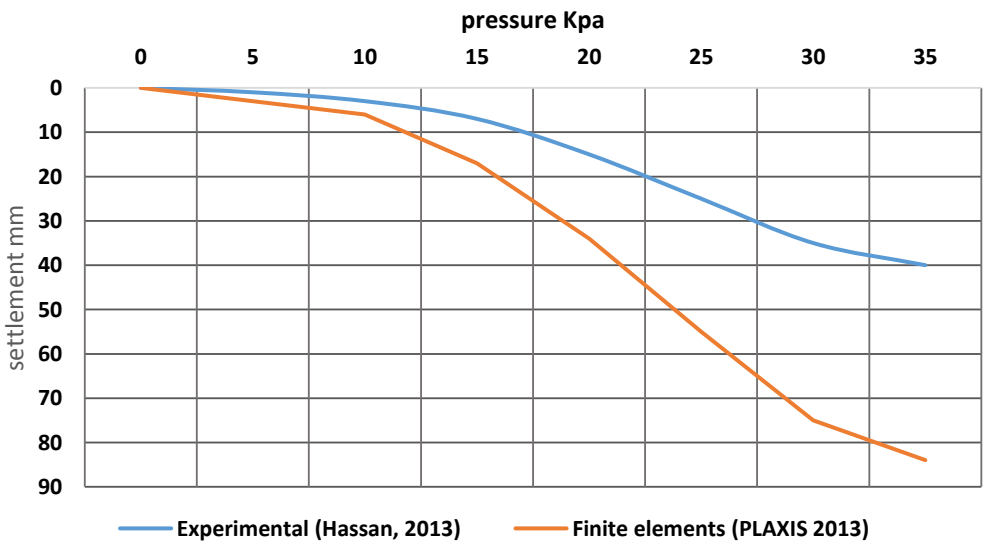


Fig. 8. Results of bearing pressure versus surface settlement relationship of embankment model 200 mm high resting on soft soil treated with encased stone column at (s=2.5d)(L/d=5)

Analyses results

For each stresses applied, the resulting maximum deformation at the foundation is evaluated , the figures above shown the maximum deformation under applied stress ,A summary of settlement results are given in Table of **Hassan2013** Settlements evaluated from the finite element analyses are compared to those measured during the group load test at the field and those obtained from empirical correlations. Figures above shows the pressure - displacement curves resulting from elastic settlement calculations, load test on group of columns with/without using geogrid material and finite element model analyses, tabel below shows the final compare result between finite element model and experimant result

Table 2. Final result of compare the result between finite element model and experiment result

Settlement mm	**Pressure Kpa**						
	5	**10**	**15**	**20**	**25**	**30**	**35**

Without Geogrid	L/D=8	Hassan2013	2	2.5	4	8	15	22.5	35
		PLAXIS 3D	1.5	3	6	11	16	25	37
	L/D=5	Hassan2013	1	2.5	7.5	15	30	-	-
		PLAXIS 3D	1.5	2	8	18	33	-	-
Encaed with geodrid	L/d=8	Hassan2013	1	3	7	15	25	35	40
		PLAXIS 3D	2	3	11	20	27	39	49
	L/d=5	Hassan2013	1	3	4	5	11	20	27
		PLAXIS 3D	1	4	3	7	16	29	33

Conclusion

A set of three-dimensional parametric numerical analyses were performed on untreated soft soil and soil treated with ordinary and encased stone columns. The long term behavior of embankment resting on encased stone columns in terms of vertical settlement, lateral displacement, and excess pore water pressure were studied. Parameters like stone columns diameter, distance between columns, stone columns length, encasement, encasement length, encasement stiffness, undrained shear strength, and soft soil permeability were examined.

From the present study, the following conclusions can be drawn:

1. The study shows that the time-dependent behavior of embankment resting on encased stone columns can be analyzed using the finite element program PLAXIS 3D, and that the hardening soil mode (HS) may provide a realistic stress distribution with the soft soil mass beneath the embankment.
2. The improvement in settlement of ESC increases as the spacing ratio of stone columns (S/d) decreases. The highest percentage of decrease in settlement relative to untreated embankment of (L/d=5) are found to be (49.83%) for S/d (2.5). On the other hand, the decreasing percentage of L/d=8) is (68.86 %) for S/d (2.5). The lowest value of settlement improvement ratio at failure was observed at S=2.5d for a given embankment height, which represents higher degree of improvement.

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