Numerical Model of Stone Column in Sabkha Soil

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Abstract - **Soil improvement by means of stone column method is used to improve sabkha soils in order to limit total and differential settlement and to achieve the required bearing capacity. Full-scale plate test was performed on site to confirm the achievement of required bearing capacity at the specified settlement. Despite the fact that this technique is widely used to improve sabkha soils, there are no studies focusing on the behavior of stone columns in such problematic soils. Sabkha soils are known for its high compressibility, low strength and water sensitivity due to loss of salt cementation upon flooding during installation of stone columns. Numerical modeling of plate load test assist to understand complicated behavior of sabkha – stone column interaction. This paper presents a three-dimensional Finite element model, using PLAXIS 3D software, to simulate vertical plate load tests on a stone column installed in sabkha. The predicted settlement values are in reasonable agreement with the field measure values and the field load - settlement curve can be predicted with good accuracy.**

Keywords: stone column, sabkha soils, Numerical, PLAXIS 3D.

I. INTRODUCTION

The site under consideration is located in Jubail industrial city in the Eastern province of Kingdom of Saudi Arabia. The project proposes a Fire and Service Water (FSW) tank with overall diameter of 71m and height of 20m. The eastern coastal plain of Saudi Arabia is low in elevation and is covered with quaternary sediments of salt-bearing deposits, sand dunes, sabkha and outcrop of calcareous and sandstones. Sabkha is a saline deposit generally consisting of saturated loose silty sand and possibly clay [1], [2]. Structures constructed on sabkha soil experience several problems including excessive settlements, and low bearing capacity and thus inability to carry loads safely [3]. One of the best remedial measures for overcoming these problems is to improve the sabkha using stone columns.

Stone columns in general, are used to improve soft ground by sharing load carrying capacity with the soft ground and thus reducing settlement. In addition, the stone column itself acts as vertical drain which promotes accelerated consolidation [4]. The methods used to design stone columns on soft soil generally are based on the assumption of approximate calculation based on elasticity and plasticity theories [5]– [7]. Filed static load test on stone columns afford an effective way to check (back calculation) on the uncertainties in the subsurface soil parameter measurement and design assumptions that are adopted in the design and construction of stone columns. Finite element methods offer an excellent opportunity to study stone column-soil interaction, stone column response and soil movement [8]. These modeling methods can be extended to simulate the stone column-loading test and analyzing the results of properly executed and documented field tests.

In this study, a composite behavior of stone columns reinforced soft ground is adopted where sabkha properties have been evaluated by field measurements and the three-dimensional modeling is utilized to predict the actual behavior of the stone column installed in different soil layers. Modeling was done using commercial finite element program PLAXIS 3D. The load-settlement curve measured in the field was compared with the settlement calculated from the model.

II. SOIL LAYERS' CONDITIONS AND IMPROVEMENT WORKS

Geotechnical investigation was carried out at the proposed tank locations to determine the subsurface stratigraphy, groundwater conditions and to evaluate the engineering characteristics of the representative soil profiles in the project site. Soil profile showed that the top 1.5 m layer consists of poorly graded, fine to medium sand with silt in loose to medium dense condition. The sand layer is followed by very loose (soft) to medium dense sabkha to a depth of about 6m. This sabkha layer is underlain by interbedded sand with silt layers in various compact conditions and consistencies. Ground water was encountered at depths of 1.25m below the ground level. The variation of SPT-N values with depth and soil type under tank is summarized in Table 1. The ground underneath the tank were improved by the installation of 2065 stone columns to depth 10m in a regular 1.7m×1.7m triangular grid with a nominal diameter of 1m using wet Vibro replacement method. The stone columns extend from existing ground level to the load bearing dense sand layer at an approximate depth of 10m.

III. FULL SCALE PLATE TEST

In order to assure the required design capacity under tank, two plate load tests were carried out on a single stone column. The size of the test footing was 2m× 2m×0.6m. Load was applied in two cycles; for the first cycle the design load (100%) was applied and maintained for 24 hours. In the second cycle, a maximum load of 150% of design load was applied for the test. The load was applied using a hydraulic jack of 200 ton capacity reacting against a kentledge platform of concrete blocks. The results of the load tests are plotted in forms of load-settlement as shown in Figure 1(b).

Pre- and Post-CPTs were carried out as shown in Figure 1(a), to evaluate the improvement in ground properties as a result of vibro flotation. The proposed locations of three Post CPTs were tested at different distances around stone column. The first was in the center of the group of stone columns, the second in the center of two stone columns, and third was 600mm away from the center of stone column.
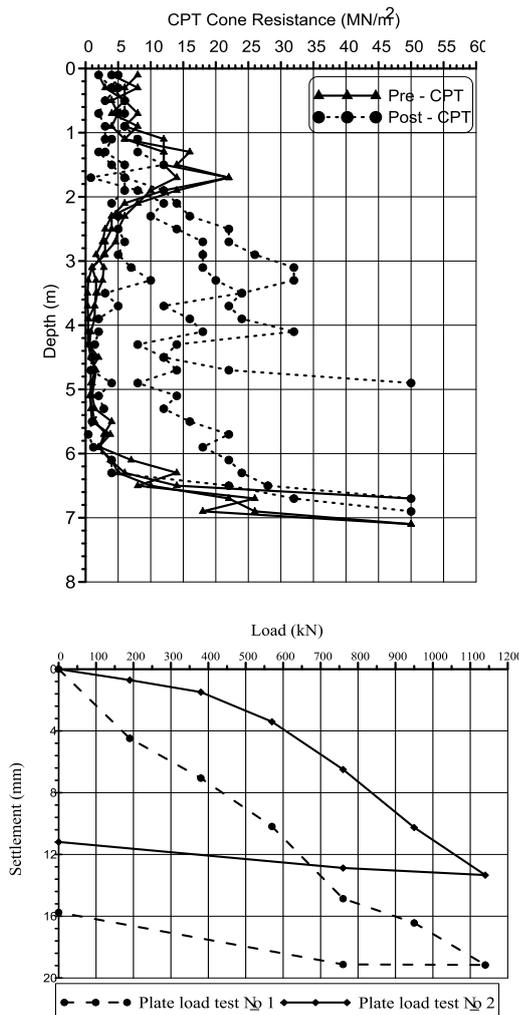

Figure 1: Field test in the tank area, (a) Pre- and Post-CPT results and (b) plate load test results

IV. NUMERICAL MODEL

The numerical modelling was carried out using Plaxis 3D V. 2013. All soil layers were modeled using the elastic-perfectly plastic Mohr-Coulomb model. The soil layer parameter was chosen on the basis of the boreholes conducted near the plate load test location; the values are shown in Table 1. The elastic modules values of the top sand layer, sabkha layer and medium dense sand layer were calculated from the post-improvement CPT's value since these layers were slightly improved during the installation process of stone columns. The modulus values for soil layers under stone column were calculated using average values of SPT N–values.

TABLE 1
Soil Constitutive Model Parameters Adopted for the Design of Stone Columns

Depth, m	Soil Type	Average SPT-N Values	Angle of Internal Friction (Degree)	E MN/m^2
G.L to 1.5	Sand (recent backfill)	9	30	18
1.5 to 6.00	Sabkha	3	25	5
6.00 to 11.5	Medium dense sand	16	34	40
11.5 to 25	Very dense sand	50	38	60
Cohesion kPa = 0 for all soil layers				

A precast concrete footing was modeled as an elastic non-porous material. Stone column was modeled using Mohr-Coulomb model, and full drain due to a high permeability of the crushed stone [9]. The elastic modulus and poisson's ratio of stone column materials is assumed based on [10]. No interface element was used between the stone column and surrounding soils. This is justified by the mixing which occurs around the stone columns between crushed stone and surrounding soils during the installation process. The properties of the stone column materials and concrete footing adopted in the model are shown in Table 2.

15-node wedge elements were used in the model with very fine mesh in the area around the tested stone column, and medium mesh size for the remaining area. The basic symmetry and finite element mesh used to represent model is shown in Figure 2. The boundaries of the numerical model were extended to 9m×9m in order to minimize the effects of model

boundaries on the analysis. The height of the model was selected as 25m. The initial stress condition prior to the installation of the stone columns was generated using the K0 approach. A static pore water pressure profile was generated based on the location of the groundwater table, which was set at 1.25m below the ground surface.

TABLE 2
Material Properties of Stone Columns and Precast Concrete Footing

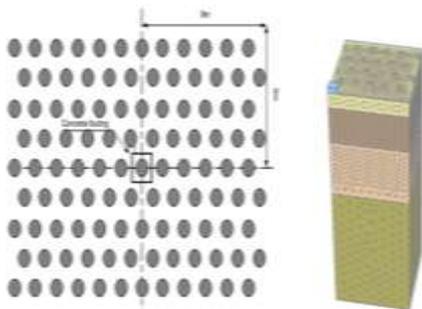| Material	Constitutive Modle	Parameter	Value
Stone column	Mohr-Coulomb	Elastic modulus E (MPa)	40
		Dry Unit Weight (kN/m3)	20
		Sat. Unit Weight (kN/m3)	20
		Poisson'sratio	0.33
		Internal friction angle (°)	42
Concrete Footing	Linear-Elastic	Elastic modulus E (MPa)	31×10^3
		Dry Unit Weight (kN/m3)	24
		Poisson'sratio	0.1

Figure 2: Symmetry area considered and finite element mesh

V. RESULTS AND DISCUSSIONS

Figure 3 presents the computed and measured results for the single stone column under compressive loads. The comparison of the computed and measured settlements of the

stone column shows a good agreement between the numerical result and the filed load test.
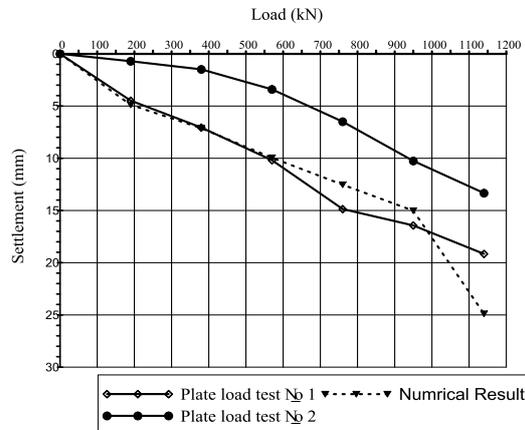

Figure 3: Comparison between filed and numerical settlement

Figure 4 presents the stone column bulging curves with depth for the stone column obtained from the numerical analysis. The bulging along the stone column occurs within a range of approximately 4.5m under the bottom of the precast concrete footing. This bulging depth range is approximately 4 times the diameter of the stone column. The location of the maximum bulging is at a depth of approximately 2.5m from the bottom of the precast concrete footing.
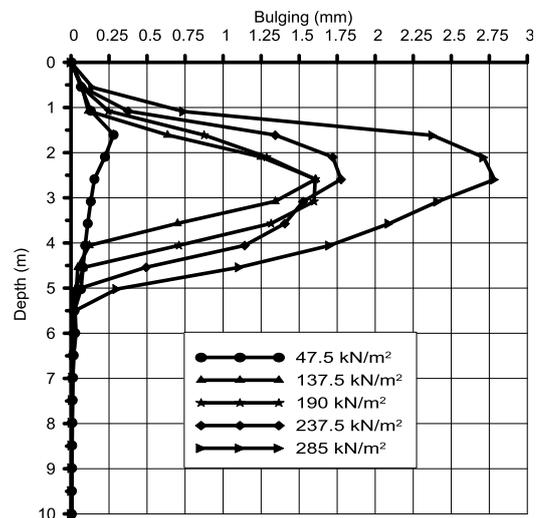

Figure 4: Stone column bulging–depth curves

VI. CONCLUSION

Three-dimensional numerical analysis has been carried out to model the plate load test on a single stone column reinforced sabkha soil. The bearing pressure-settlement of the field test and numerical result was approximately similar. The finite element model, once calibrated by these field data, can be used as a powerful tool to investigate the effects of stone

column on different improvement geometries and material properties. This will be used for design optimization of stone columns in sabkha soil; however, more field data is needed to validate the approach.

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