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Behavior of Foundations on Reinforced Sabkha Soil: A Numerical Study

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Authors' contributions

This work was carried out in collaboration between both authors. Author LS designed the study, performed the experimental study, managed the literature searches. Author KMMB wrote the protocol and the first draft of the manuscript, managed the numerical analyses of the study. Both authors read and approved the final manuscript.

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ABSTRACT

The aim of this research is to investigate numerically the behavior of strip footings resting on Sabkha soil reinforced using two methods. Firstly, using a layer of compacted sand reinforced with random distributed fibers beneath footing. Secondly, using a layer of compacted sand reinforced with geogrids.

The benefit of mentioned two methods on the improvement of strip footings bearing capacity and decreasing the settlement was investigated using a finite element computer program Plaxis 2D ver. 8.6. It was found that using two methods increases bearing capacity of strip footings significantly specially using first method (fiber reinforced sand layer). It was observed also that the settlement decreased for the same stress values.

Keywords: Strip footings; sabkha soil; bearing capacity; fibers; geogrids; finite element; plaxis.

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1. INTRODUCTION AND PREVIOUS RESEARCH

Sabkha soils are coastal and inland saline deposits of arid climates consisting mainly of loosely cemented sandy silt to silty clay particles. Sabkha soils are found in many parts around the world specially in hot and arid countries like the coasts of Middle Eastern and North African countries as shown in Fig. 1. These soils are very compressible specially upon wetting, therefore are considered a risky soil to construct on.

Many methods were used to improve the sabkha soil such as chemical stabilization, mechanical stabilization like vibroflotation, stone columns, dynamic compaction. The previous research include works done by:

Abduljauwad, et al. [1] used conventional approach and Soil Fabric Aggregate (SFA) under the static and the dynamic loading conditions to investigate the performance of Sabkha subgrade in laboratory. The main aim of their research was to evaluate the influence of geotextiles on the performance of Sabkha subgrade. Various parameters were used including sub-base thickness, geotextile type, loading and moisture conditions. They found that the geotextile incorporation with SFA systems for both the dry and saturated conditions increased the ultimate strength of Sabkha soil. The results conclude that Sabkha with geotextile carry higher loads than Sabkha systems without geotextile for both dry and saturated conditions. Fouad, et al. [2] they studied experimentally the effect of Geotextiles on top of salt-encrusted soil, known as sabkha found in the Arabian Gulf area, as a subgrade layer. An experimental model was developed in the laboratory to evaluate the bearing capacity and resistance to permanent deformation of the soil–fabric-reinforced system. The results indicate that the use of geotextiles significantly improved the bearing capacity and resistance to permanent deformation of the base layer on top of a sabkha subgrade especially in saturated conditions. Siddiqi [3] used geotextiles in his research to improve the load carrying capacity of pavements constructed on Sabkha Soil. He investigated the effect of geotextile grade, thickness of base, type of loading and moisture effect on the performance of SFA systems. He used three different percentages (5, 7 and 10%) of cement as stabilizing agent. The results indicated that the application of geotextile in road construction on Sabkha subgrades had improved load carrying capacities, specially under the soaked conditions. Aiban, et al. [4] used geotextile and Portland cement for upgrading the load carrying capacity of Sabkha Soil which was used as subgrade material. They also investigated the impact of these two techniques on the performance of the SFA systems. They used non-woven and needle-punched, polypropylene geotextiles with three different grades of geotextile which have different tensile strength & unit weight. Three different dosages (5, 7 and 10%) of cement was used as stabilizing agent. They also found the almost similar findings that suggested the systems with geotextiles can carry more loads than the systems without geotextiles specially for the saturated conditions. Omar Saeed Baghabra [5] studied the effect of adding lime and cement at various dosages for stabilization of Sabkha soil found in eastern Saudia Arabia. results of the study indicate that sabkha can be practically used by the construction industry in many field applications. Hassan Obaid Abbas [6] used Geomesh and Addition of Polycoat for improvement of sabkha soil. He conducted experimental model tests. In this study two types of improvement are used. the first improvement consists of using fine geomesh under footing at different depth (0.5B, B,2B), the second improvement is the addition of polycoat with different concentration to surface of soil. The first method does not give good results of improvement but the second method gives good improvement which reduces the collapsibility to 62% at stress level of 50kPa. Al-Alusi, et al. [7] studied the effect of a series of large scale ground improvement trials undertaken at MASDAR City area, Abu Dhabi, Emirate in order to ascertain the field performance of a range of ground improvement techniques using columns. It was found that grouted stone columns and sand cement columns can offer significantly higher degrees of ground improvement with only modest additions of cement and/or grout. Benmebarek, et al. [8] conducted a numerical study of embankment reinforced by geosynthetics on sabkha soil. The main purpose of their study was to assess the effect of reinforcement by geosynthetic on the construction embankment layer quality, the settlement and stability of the embankment. They found that the reinforcement does not have a significant influence on the absolute settlement of the embankment but, improves the conditions of implementation and the quality of the embankment, especially under wet conditions. In addition, the use of reinforcement in

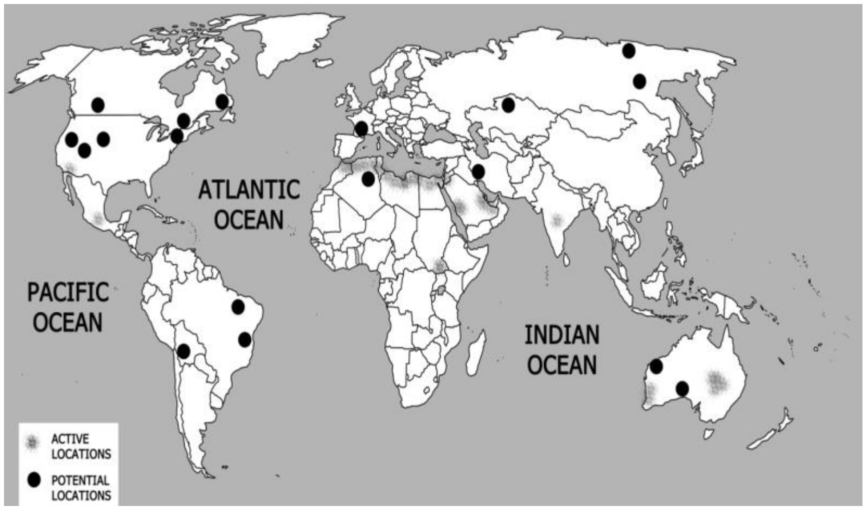

Fig. 1. Distribution of sabkha soil around the World
(According to Alnuaim AM, et al.)

embankment construction may allow for an increase in the design factor of safety and, an increase in the height of the embankment. Alnuaim and Naggar [9] they studied the performance of shallow foundations on sabkha soil. They conducted a numerical analysis based on a large number of laboratory tests to determine the shear strength and stiffness parameters of the sabkha soil. The developed numerical model was verified using the results of full-scale pile load testing program from an ongoing project to further enhance the accuracy of the results. It was found that the failure mode was generally a general shear failure for footing diameter to sabkha thickness ≤ 1, and the punching shear for ratios greater than 1 due to the presence of the loose soil layer underneath the sabkha. Thus, the general bearing capacity equation can be used to predict the capacity of footings founded on sabkha as long as the footing diameter ratio to sabkha thickness is < 1. Joon-Shik, et al. [10] studied the effect of dynamic compaction on bearing capacity of sabkha soil. They evaluated ground behavior during dynamic compaction for various compaction energy conditions using numerical analysis. field dynamic compaction tests were also performed and compared with the numerical analysis results. It was found that the bearing capacity of sabkha deposit can be effectively improved by dynamic compaction. Hassan [11] conducted a numerical study of the behavior of sabkha soil reinforced using stone columns. The numerical study was conducted using plaxis 3d software. The results obtained from numerical model was compared with actual load-settlement curve obtained from field plate load test. The comparison of the computed and measured settlements of the stone column shows a good agreement between the numerical result and the field plate load test.

2. EXPERIMENTAL WORK AND MATERIAL USED

The research is based on a borehole at Jubail City area, eastern Saudi Arabia. The soil profile consists of a top layer of fine to medium sand of thickness 1.5 m followed by a thick layer of sabkha soil to depth of 6 m, finally a layer of medium to dense sand to the end of boring. The ground water table was at 1.25 below ground surface. The following table shows the properties of soil in site.

Table 1. Soil properties in site

Depth (m)	**Soil type**	**SPT values**	**Angel of shearing resistance (ϕ°)**	**Cohesion *C***	**Modulus of elasticity *E* (kN/m^2)**
0 - 1.5	Sand	9	30	0	18000
1.5 - 6	Sabkha	3	25	0	5000
6 – 11.5	Medium Sand	16	34	0	40000
Below 11.5	Very dense Sand	50	38	0	60000

Fiber: Fibermesh Europe Ltd., Chester field, England produces the polypropylene fiber used in this research. The fiber product name is LH 7350 having length of 19 mm. The properties of fiber are shown in Table 2.

Geogrid: Homogenous (HDPE) geogrid type was used in this study having the following properties illustrated in Table 2.

2.1 Numerical Model Setup

Numerical analysis using the finite element method (FEM) was carried out using plane strain elasto-plastic finite element method software (PLAXIS 8.6). The soil was modeled using well-known Mohr-coulomb model which has been considered as a first order approximation of real soil behavior.

It involves five input parameters, including cohesion (effective) *C*, angle of internal friction (effective) ϕ, angle of dilatancy ψ, primary loading stiffness *E* and poisson's ratio μ. A strip footing of width equal to 1 m was placed on the soil surface exactly at the center of the soil model. 15-noded triangular elements were used. The boundaries are laterally fixed on both sides, horizontally and vertically at the bottom boundary. The footing was modeled as a rigid plate element. Geogrids were modeled using elasto-plastic constitutive model. Table 4 shows the properties of materials used in finite element study.

2.2 Two Methods of Reinforcement were Studied as Following

Method 1 using Fiber reinforced sand layer: In this method a layer of sand reinforced randomly with fibers beneath the footing was used as shown in Fig. 3. The optimum percentage of fibers was selected to be 1.5% of dry weight of sand. This value was obtained from direct shear tests. The effect of fiber reinforced layer thickness (H_f) on the load carrying capacity of footings was investigated where various thickness of fiber reinforced sand (H_f/B) = 0.5, 1, 1.5 and 2 was used.

Method 2 using Geogrids: In this method a layer of compacted sand reinforced with Geogrids beneath the footing was used as shown in Fig. 4. The effect of number of geogrid layers (*N*) and width of geogrids (*L*) on the load carrying capacity of footing was studied. The lengths of geogrids studied was *5B*, *6B* and *7B*. depth of first layer of reinforcement from the bottom of footing and was chosen to equal 0.25 footing width *B* (*u=0.25B*). The vertical spacing between geotextiles layers were equal to *0.25B*.

Figs. 5 to 10 show the deformed mesh of the model and vertical displacement after application of footing load in case of unreinforced sabkha soil and for two methods of reinforcement.

Figs. 11 to 13 show the stress distribution after application of footing load in case of unreinforced sabkha soil and for two methods of reinforcement.

Table 2. Properties of fiber

Property	Value
Density	9.53 kN/m^3
Melt index	0.35 gram/10 minutes
Tensile strength, break	26.9 kN/m^2
Flexural modulus	1275.5 kN/m^2
Tensile impact	252 kJ/m^2
Hardness, shore *D*	66
Environmental stress crack	50 hrs
Specific gravity *Gs*	0.9
Resistance, *Fso*	> 500 hrs

Fig. 2. Photography of polypropylene fiber

Table 3. Properties of geogrid

Property	Maximum tensile strength (kN/m)	Equivalent depth *d* (mm)	*EA* (kN/m)
Value	90	15	1020

Table 4. Summary of materials parameters used in the finite element study

Material / Parameter	Footing	Geogrid	Fiber reinforced sand soil	Sabkha soil	Medium sand soil
Unit weight (kN/m^3)	25	-----	18.7	18.5	18
Modulus of elasticity *E* (kN/m^2)	2.1*10^7	------	48000	5000	40000
Poisson ratio (μ)	0.1	-----	0.3	0.3	0.3
Angle of internal friction (ϕ°)	----	----	39°	25°	34°
Cohesion *c* (kN/m^2)	-----	------	0	0	0
Dilatancy angle (Ψ°)	----	----	9	0	4
EA (kN/m)	---	1020	-----	-----	----

Where: EA: Axial/Normal Stiffness for Geogrids

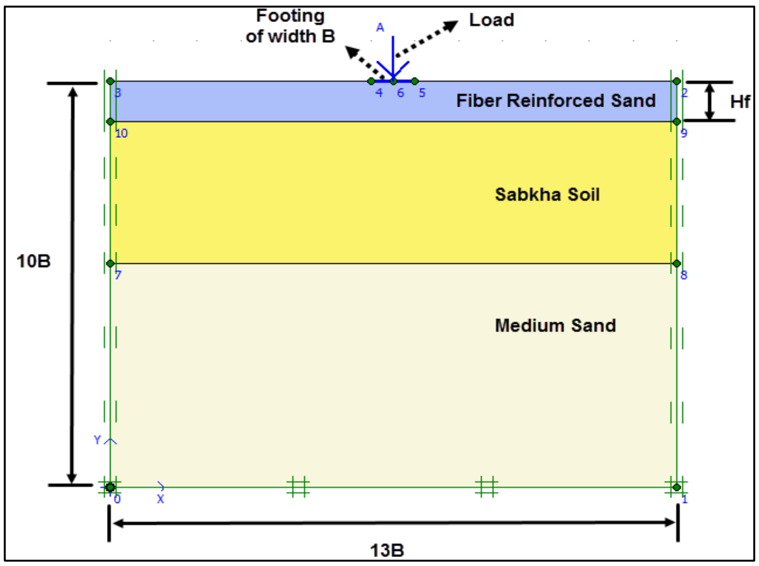

Fig. 3. Finite element model in case of using fiber reinforced sand

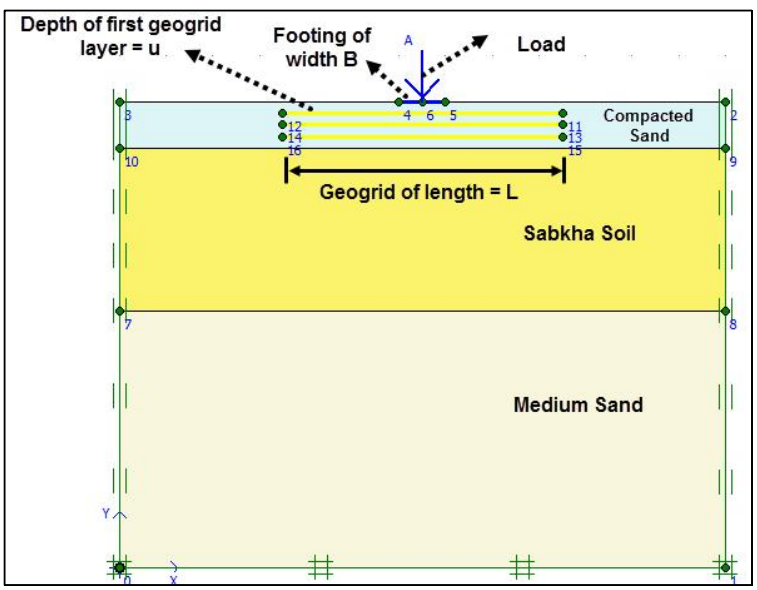

Fig. 4. Finite element model in case of using geogrids

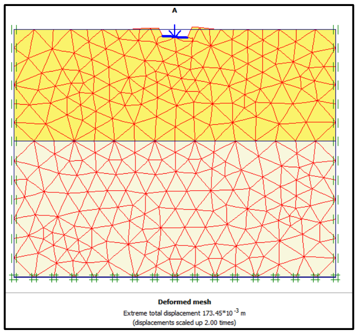

Fig. 5. Deformed mesh for unreinforced sabkha

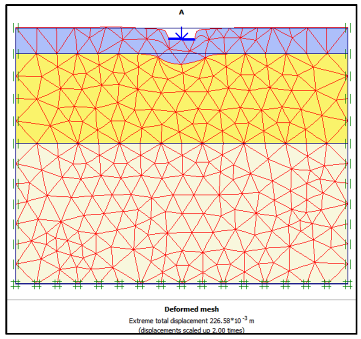

Fig. 6. Deformed mesh in case of fiber reinforcement

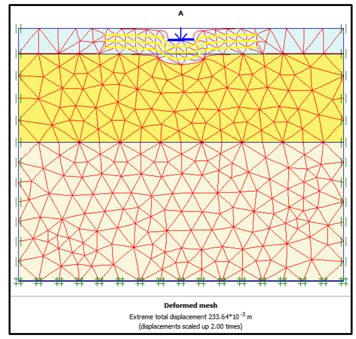

Fig. 7. Deformed mesh in case of using geogrids

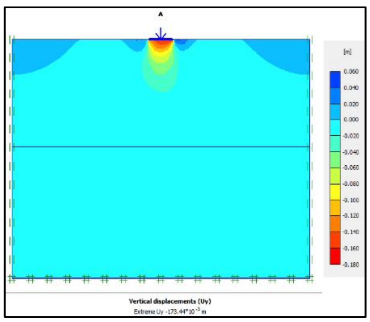

Fig. 8. Vertical displacement for unreinforced sabkha

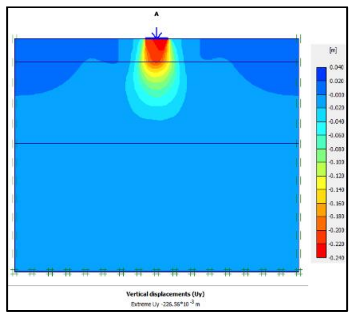

Fig. 9. Vertical displacement in case of fiber reinforcement

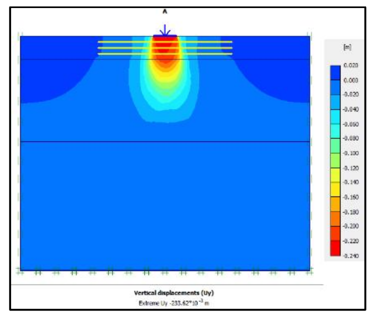

Fig. 10. Vertical displacement in case of using geogrids

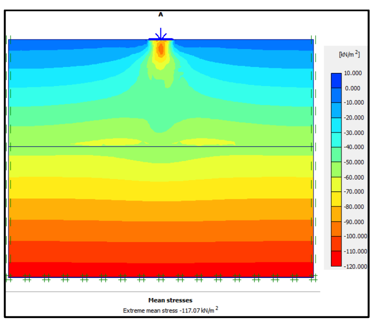

Fig. 11. Mean effective stress distribution for unreinforced sabkha

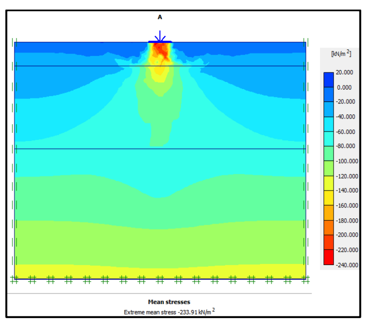

Fig. 12. Mean effective stress distribution in case fiber reinforcement

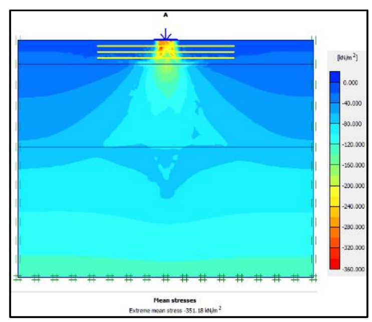

Fig. 13. Mean effective stress distribution in case of geogrids

3. RESULTS AND DISCUSSION

3.1 Effect of Fiber Reinforcement

The results are presented as a relationship between the footing stress versus corresponding settlement. Fig. 14 shows the relationship between footing stress versus settlement in case of using first method of reinforcement (Fiber reinforced sand) for different thickness of fiber reinforced sand layer. It was observed that using randomly distributed fibers increases the ultimate bearing capacity of footing significantly from 108 up to 400 kPa (270%) in case of using fiber reinforced layer of thickness equal two times the footing width. The improvement in bearing capacity is because the reinforced fiber sand layer can sustain higher stresses compared to unreinforced sabkha soil due to the new load distribution provided by the fiber reinforcement and the increase in shear strength parameters of sand soil beneath the footing resulting from inclusion of fibers. It was found also, that settlement decreases for the same stress values.

3.2 Effect of Geogrid Reinforcement

Several lengths of Geogrids were studied and the effect of no. of Geogrids layers was also studied. Results obtained using various Geogrid configurations is shown in Table 5. From Table 5 the optimum length of Geogrid obtained was equal six times the width of footing *L=6B*. It was found that maximum percentage increase in ultimate bearing capacity was 107% when using 3 layers of Geogrids of length *L = 6B*. The improvement in bearing capacity in case of using Geogrids because they decrease the lateral movement of the soil and distribute stresses on a wider area. Fig. 15 shows the relationship between footing stress versus

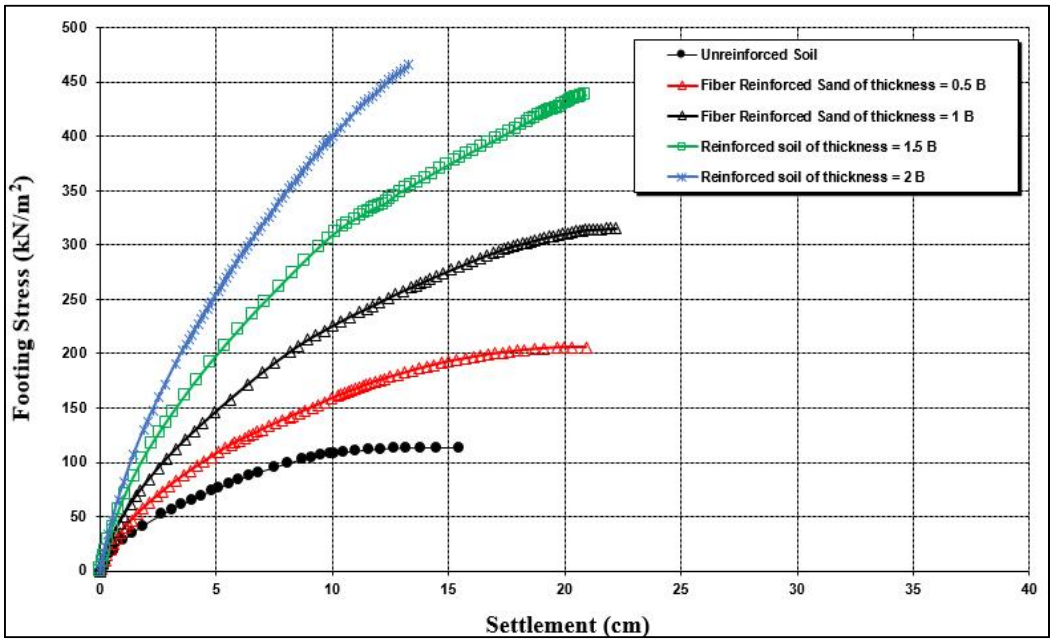

Fig. 14. Footing stress vs settlement in case of using fiber reinforcement

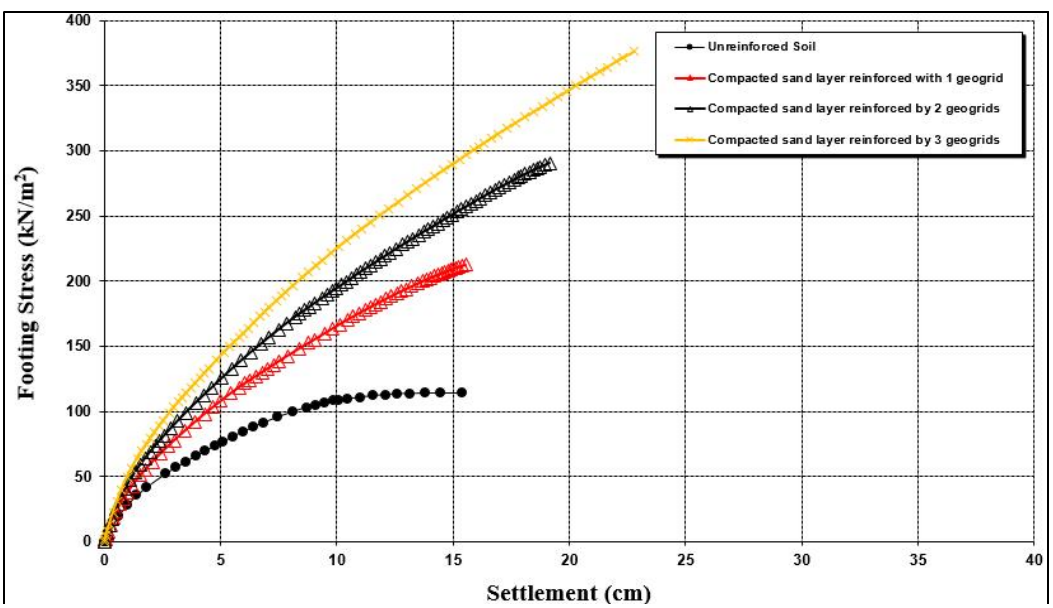

Fig. 15. Footing stress vs settlement in case of using geogrid reinforcement

Table 5. Ultimate bearing capacity values for various geogrid lengths and numbers (Bearing capacity of unreinforced soil = 108 kN/m^2)

Geogrid length (*L*)	No. of Geogrids layers (*N*)	Ultimate Bearing Capacity (kN/m^2)	Percentage increase in ultimate bearing capacity (%)
5B	1	159	47
	2	188	74
	3	203	88
6B	1	165	53
	2	195	80
	3	224	107
7B	1	159	47
	2	186	72
	3	220	103

settlement in case of using Geogrids of length = *6B*.

4. CONCLUSION

The aim of this research is to investigate numerically the effect of using a layer of compacted sand reinforced with random distributed fibers beneath footing. Also, using a layer of compacted sand reinforced with Geogrids on the load carrying capacity of strip footings resting on Sabkha soil.

Based on the numerical analysis results, the following conclusions obtained:

- It was concluded that bearing capacity of footing on Sabkha soil was significantly improved using a layer of sand reinforced randomly with fibers, also the bearing capacity improved using Geogrid reinforcement.
- For case of using fiber reinforcement the maximum percentage increase in bearing capacity was 270%.
- For the case of using Geogrids the maximum increase in bearing capacity reached 107%.
- It was found that the optimum width of Geogrid equal 6 times the footing width (L=6B).
- For both methods it was noted that the increase in bearing capacity is associated with a decrease in settlement for the same stress value.
- It can be concluded that the use of fiber reinforced sand as reinforcement layer below foundation resting on Sabkha soils is very promising as well as using Geogrids

5. DIRECTIONS FOR FUTURE RESEARCH

- A comparison of this research results with those of experimental model or field full scale tests may be investigated.
- A comparison of current research results obtained using Plaxis 2D software with results obtained in case of using other finite element method software like Plaxis 3D may be investigated.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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