SVU-International Journal of Engineering Sciences and Applications (2023) 4(2): 36-46
Print ISSN 2785-9967 | Online ISSN 2735-4571
DOI 10.21608/svusrc.2023.186565.1094

Numerical Simulation of Strip Footing Behavior on Reinforced Sabkha Soil

**Lamiaa Eied Sadek[1], Khaled M. M. Bahloul[2,] **
(https://orcid.org/0000-0002-2905-5182- https://orcid.org/0000-0002-9834-3815)

Abstract Sabkha soils can be found all over the world specially, in hot arid areas. This soil is regarded as problematic because of its low bearing capacity and excessive settlement which creates problems to any type of structures. Consequently, the aim of this paper is to predict the behavior of strip footing founded on reinforced Sabkha soil using three different methods utilizing finite element method analysis. First, beneath the footing, a compacted sand layer mixed with randomly dispersed polypropylene fibers (PP) is used. Moreover, a compacted sand layer reinforced with geogrids is used. Finally, investigate the effect of using a sand-rubber mixture layer below as a foundation soil below the footing. The effects of these methods on strip footing bearing capacity and settlement were studied using the finite element method software Plaxis 2D ver. 21. Therefore, it was determined that adopting these procedures boosts the strip footing bearing capacity by a substantial amount, particularly when utilizing the first method which is utilizing the fiber reinforced sand layer over the weak sabkha soil layer. Also noticed was a reduction in soil vertical displacements under foundation for the same values of stress applied to footing.

Keywords Strip Footings, Geogrids, Reinforced Sabkha Soil, polypropylene fibers, Rubber

1 Introduction

Sabkha or saline soils form in arid regions as a result of sea level drop during the quaternary and recent ages, which is followed by evaporation **[1-2]**. Environmental factors such as wind, temperature, and biological activity all played a role in the formation of sabkha. Sabkha, in general, is made up of sand deposits mixed with silt and clay and is formed by evaporates **[3-4].** Sabkha can be classified into two types of soil: sandy sabkha and muddy sabkha **[5].** Salts partially cement sandy sabkha, which ranges from very loose to medium dense.

Muddy sabkha are lagoon sediments made up primarily of sandy carbonate muds. The salt constituent is crucial in determining the geotechnical properties of sabkha soil. The salt-encrusted surface of the sabkha is stiff and durable during the dry seasons, but soft and muddy when wet from rain **[6-7].**

The majority of the particles that make up Sabkha soils are carelessly cemented sand, silt, or silty clay particles discovered in inland and coastal areas of arid climates. Sabkha soils can be found as muddy or sandy sabkha all over the world, although they are most common in hot arid areas, such as the North Africa and Middle East coasts, as well as along the Red Sea and Arabian Gulf in Saudi Arabia as shown in fig. (1).

This soil is regarded as problematic soil because, when wet, it is prone to heaving as a result of the salt crystallization/re-crystallization process, as well as collapse as a result of the dissolution of cementing components and the corrosion effects. In sabkha areas, numerous geotechnical problems have been reported due to the weak soils in such areas as well as rise water table level and its high salinity. In general, sabkha sediments are characterized by high void ratios and low dry densities. Damage due to excessive settlements is evident in structures built on this type of soil.

Received: 11 January 2023 / Accepted: 19 February 2023
Corresponding Author Khaled M. M. Bahloul[2], E-mail: khaled_bahloul1@yahoo.com
Lamiaa Eied Sadek[1], E-mail: lamiaaeied@gmail.com
1. October High Institute of Engineering and Technology, Egypt
2. October High Institute of Engineering and Technology, Egypt

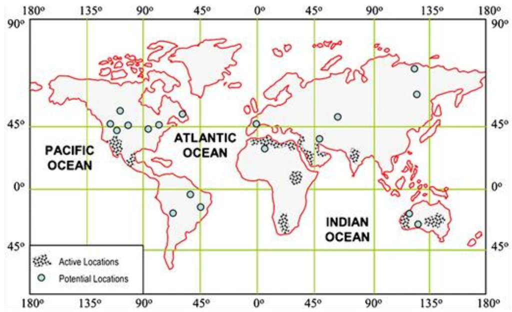


Fig. 1 Sabkha Soil locations around the World [1]

Chemical and mechanical stabilization including vibro flotation, dynamic compression, and columns were all employed to enrich the Sabkha soil.

Sabkha is an Arabic term that refers to salt-encrusted flats that are underlain by silt, sand, or clay soil.

The arid climate zone covers roughly one-third of the global land surface. This region is distinguished by a substantial lack of precipitation as well as potential moisture losses due to evaporation **[8]**. Unconsolidated, cemented, heterogeneous, sedimentological, and submerged in extremely concentrated subterranean brines are typical descriptions of sabkha soils. It has a moderately hard crusty surface and is typically made up of quartz sand, silt, and little amounts of mud and clay.

Aragonite, gypsum, anhydrite, and halite are the four principal cementing minerals, and their distribution varies from place to place. Vertical and horizontal reinforcements are included to increase carrying capacity and reduce predicted settling of shallow foundations **[9]**. Geogrids could be an appropriate and cost-effective method for enhancing load carrying capacity or soil bearing and reducing soil settlement. The displacement of the associated soil-strengthening is what causes the rise in soil shear strength that is often seen with reinforced soil.

A study was conducted by **[1,10]** to assess the impact of geotextiles on the functioning of the Sabkha subgrade. Subbase thickness, loading, geotextile type, and moisture conditions were all taken into account. They discovered that incorporating geotextiles with SFA systems increased the greatest intensity of Sabkha in both dry and saturated conditions. The both dry and wet situations, the findings show that Sabkha structures with geotextiles can withstand higher loads than those without.

According to **[11]** research, geotextiles were used to boost the load-bearing capability of Sabkha Soil pavers. He explored the influence of base thickness, geotextile class, possible entry, and humidity on the behavior of SFA systems. As a stabilizing agent, he used three different percentages of cement (5, 7, and 10%). Geotextile enhanced load bearing capacity on Sabkha subgrades, particularly in rainy situations.

Portland Cement and geotextile are employed by **[12]** to boost the load-bearing capability of the subgrade material Sabkha Soil. They also examined how these two strategies influenced the performance of SFA systems. They utilized three distinct types of needle-punched and nonwoven polypropylene geotextiles with varied strength properties and unit weight. As a stabilizing agent, 3 distinct cement concentrations were employed: 5, 7, and 10%. Moreover, similar findings suggested that geotextile-enhanced systems can convey more loads than non-geotextile-enhanced systems, particularly in saturated conditions.

Geomesh and Polycoat addition to improve sabkha soil used by **[13]**. He tested laboratory models. In this study, two types of enchantments are used in this research. The first approach involves placing fine geomesh beneath footings at different depths (0.5B, B, and 2B), while the second involves applying polycoat at varying concentrations to the soil's surface. The first approach does not lead to significant improvements, however the other way does, with a 62% reduction in collapsibility at a stress level of 50kPa.

A mathematical analysis was performed by **[14]** of a geosynthetic-reinforced embankment on sabkha soil. The major objective of their research was to examine how geosynthetic reinforcement affects embankment integrity in a layer structure, as well as its stability and settlement. While reinforcement has little impact on the absolute the embankment settling, it does enhance the implementation conditions and embankment quality, especially in wet circumstances. Moreover, using the reinforcement in construction purposes may provide an increase in both the embankment's height and the planned safety factor.

Utilizing finite elements and analytical models, the loading carrying capability and settlement of strip footings sitting on various soil types were determined. Footing stiffness, the number of boundary elements, geogrid size, and geogrid layer spacing are the studied parameters. According to the findings, the geogrid increased the footing's load - carrying capacity and reduced settlement. With three layers, the ideal geogrid size was three times the width of the footing. Footing rigidity changes influence stress and settlement behavior **[15]**.

[16] Changing the number and length of reinforcing geogrid strata separated by 25% of the foundation width affected laboratory stress measurements on sand reinforced with geogrid. The effects of strengthening lengths and layers on reinforced soil footing load-settlement were explored. Using laser sources (to highlight the geogrid strength) and a digital camera, we measured the soil and strengthening stratum displacements in response to strip loads. Using two-dimensional finite difference software that accounted for the shape and dimensions of the experimentally simulated tests, the geogrid portion beneath the strip loading was studied.

The length and diversity of reinforcing layers increase the capacity of load-bearing and tensile strength of the strengthened soil foundation, with the effect becoming more evident as the number of strengthening layers has risen.

[17] experimentally examines the impact of discrete and randomly dispersed fiber reinforcement on the bearing capacity of a shallow foundation. To achieve this objective, a series of centrifuge experiments were conducted on a surface strip footing under circumstances of plane strain. The results are plotted as bearing pressure vs settling ratio. The use of fiber reinforcement enhanced the carrying capacity of the foundation, decreased settlements substantially, and increased the stiffness of the reinforced surrounding soil.

The effect of using PP fiber on soil bearing capacity was investigated by **[18]**. The experimental results show that the addition of polypropylene fibers improves the mechanical properties. The insertion of fibers with random distribution has a considerable influence on the shear strength and dilatation of sandy soil. It has been established that mechanical characteristics improve with a fiber content increase of up to 0.75 percent; this enhancement is particularly noticeable at greater normal stress and relative density.

[19] A number of laboratory model studies were done to examine the usage of tire shreds as a soil-bearing capacity-enhancing reinforcement. The two most influential factors on bearing capacity are shredded content and aspect ratio. Sand is combined with tire shreds of rectangular form, 2 and 3 cm in width, and aspect ratios of 2, 3, 4, and 5. The following volume fractions were selected for shredding: 10, 20, 30, 40, and 50%. Whenever tire shredded are put to sand, the BCR (bearing capacity ratio) increases from 1.17 to 3.9 in response to the shred content and aspect ratio of the shreds. At 40% shred content and 3 x 12 cm measurements, the maximal BCR is obtained. It has been shown that increasing the amount of shred increases the BCR. Nevertheless, there is a maximum shred content beyond which increased shreds led to a drop in BCR. An aspect ratio of 4 seems to yield the highest BCR for a given shred width, shred content, and soil density.

[20] Investigated the effectiveness of footings on sabkha soil. They also carried out a theoretical study depend on several laboratory measurements to establish the shear strength and stiffness characteristics of the sabkha soil. To increase the accuracy of the results, the constructed numerical model was validated using the findings of an ongoing project's full-scale pile load assessment investigation. The failure mechanism was pure shear for footing dimension to sabkha thickness ratios below one and a punching shear for ratios higher than one owing to loose soil underlying the sabkha. As a result, if the ratio between diameter of footing to sabkha thickness is more than one, to predict the capabilities of sabkha-based footings, utilize the general load bearing capacity equation.

[21] Investigated the dynamic compaction effect on sabkha soil carrying capacity. They utilized numerical analysis to evaluate the behavior of the surface during soil compaction under varied compaction energy circumstances. In addition to the numerical study, field-based dynamic compaction experiments were conducted and compared to the findings. It was observed that dynamic compaction may substantially increase the load carrying capability of the Sabkha deposit.

[22] analyzed numerically the performance of sabkha soil strengthened with stone columns. For the numerical evaluation, Plaxis 3D software was employed. The numerical model's data was compared to the real curve of load-settlement generated from the plate load test.

Comparing the estimated and measured stone column settlements demonstrates that the calculated result and the actual plate load test agree well.

2 SOIL IN SITE AND USED MATERIALS

The study is based on a borehole in the eastern Saudi Arabian city of Jubail. The soil profile consists of a 1.5-meter-thick fine to medium sand layer, a layer of thick sabkha soil that is 6m deep, and then a medium to dense sand layer that extends to the end of boring. At 1.25 below ground level, there existed a groundwater table. The soil's characteristics are displayed in the following table.

B. WASTE TIRE SHREDS- SAND MIXTURE

The shredded tire used is fine (< 0.425mm) having the effective diameter D10 equal to 0.169mm, uniformity coefficient Cu equals 2.1 and coefficient of curvature Cc equals 1.06. Shredded tire was mixed with sand such that percentage of shredded tire was 9% of sand dry unit weight according to **[23]**.

C. GEOGRIDS

The following characteristics of the homogenous (HDPE) geogrid type employed in this investigation are shown in table (3).

Table 1. Stratification of soil and its characteristics

Depth (m)	Type of soil	Internal friction angle (ϕ°)	SPT values	Cohesion C	Elasticity Modulus E (kPa)
Below 11.5	Very dense Sand	38	50	0	60000
6 – 11.5	Medium Sand	34	16	0	40000
1.5 - 6	Sabkha	25	3	0	5000
0 - 1.5	Sand	30	9	0	18000

A. FIBER

The polypropylene fiber utilized in this study is produced by Fibermesh Europe Ltd., located in Chesterfield, England. LH 7350 is the brand name of the 19mm long fiber. Table 2 displays the fiber's characteristics which obtained by the suppliers. Figure 2 shows a photography image of PP fiber.

Table 2. Characteristics of Fiber

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

Fig. 2. Image of PP Fiber

Table 3. Characteristics of Geogrid

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

2 NUMERICAL MODEL SETUP

For numerical analysis, the Plaxis2D ver. 21 software **[24]** was used coupled with using finite element method. The soil is modelled using an advanced soil model called the hardening soil model, which has ten input parameters, including angle of shearing resistance) ϕ′, cohesion C′, dilatancy angle ψ, primary oedometer load stiffness E_{oed}^{ref}, principal load stiffness E_{50}^{ref}, unload-reload Poisson's ratio υ_{ur}, failure ratio R_f, unload-reload stiffness Eur^{ref}, and finally power m in stiffness laws.

The hardening soil model parameters of the soil are presented in table 4. These parameters are estimated based on laboratory and field standard penetration tests (SPT). According to (Brinkgreve et. al. 2010) **[25]** the values of Primary oedometer load stiffness E_{oed}^{ref}, modulus of elasticity E_{50}^{ref}, unloading-reloading modulus E_{ur}^{ref} and power (m) are estimated using the following empirical formulas:

$$E_{50}^{ref} = E_{oed}^{ref} = 60000\ RD/100\ (kN/m^2) \quad (1)$$

$$E_{eur}^{ref} = 180000\ RD/100\ (kN/m^2) \quad (2)$$

m = 0.7 – RD/320 (3)

Where: RD= Sand relative Density

A 1m wide shallow foundation was put in the precise middle of the soil model on the soil surface. To improve the results, fine mesh elements were used. At the bottom border, both vertical and horizontal bounds are set laterally on both sides. A rigid plate element was used to model the footing. The elasto-plastic constitutive model was used to model geogrids. The main materials' properties used in finite element analysis are shown in Table (4).

Table 4. Input parameters used in computer program (PLAXIS 2D)

Parameter \ Material	Footing	Fiber reinforced sand soil	Geogrid	Rubber Reinforced soil	Sabkha soil	Medium sand soil	Compacted Sand
Unit weight (KN/m^3)	25	18.7	-----	16	18.5	18	19
Modulus of elasticity $E50^{ref}$ (KN/m^2)	2.1*10 7	48000	------	75000	5000	40000	45000
$E50oed^{ref}$ (kN/m^2)	-----	48000	----	75000	5000	40000	45000
$E50ur^{ref}$ (kN/m^2)	-----	144000	----	225000	15000	120000	135000
Poisson ratio (μ)	0.1	0.2	-----	0.2	0.2	0.2	0.2
Angle of internal friction (ϕ°)	----	39°	----	36°	25°	34°	37°
Cohesion c (KN/m^2)	-----	1	------	1	1	1	1
Dilatancy angle (Ψ°)	----	9°	----	6°	0°	4°	7°
Rf	-----	0.9	-----	0.9	0.9	0.9	0.9
M	-----	0.5	-----	0.5	0.5	0.5	0.5
EA (KN/m)	---	-----	1020	----	-----	----	-----

3 METHODS OF REINFORCEMENT

A. FIBER REINFORCED SAND LAYER

As shown in figure 3, With this technique, sand was utilized as a subbase that is randomly reinforced with fibers. The ideal fiber content

was discovered to be 1.5% of the sand's dry weight **[26].** Direct shear tests yielded this result. The influence of fiber reinforced layer thickness (Hf) on footing load bearing capability was examined using various ratios of fiber reinforced sand layer thickness to footing width (Hf/B) = 0.5,1,1.5, and 2.

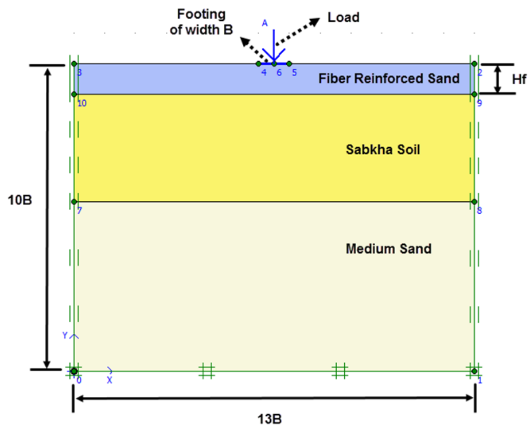


Fig. 3 Finite element model for fiber-reinforced sand or tire-waste footing

B. WASTE TIRE SHREDS – SAND MIXTURE

Same configuration as fiber reinforced sand. The optimal proportion of waste tire shreds was chosen to be 9% of dry weight of sand soil according to **[23]**.

C. GEOGRIDS

This approach supported the foundation using compacted sand and geogrids, as shown in figure 4. Investigations were done into how many geogrid layers (N) and how wide a geogrid is in relation to a footing's ability to support loads. The investigated geogrid lengths were 5B, 6B, and 7B. The initial layer of reinforcement's depth was set to be equal to 0.25 of the footing's width B (u=0.25B). Geotextile layers were 0.25B apart.

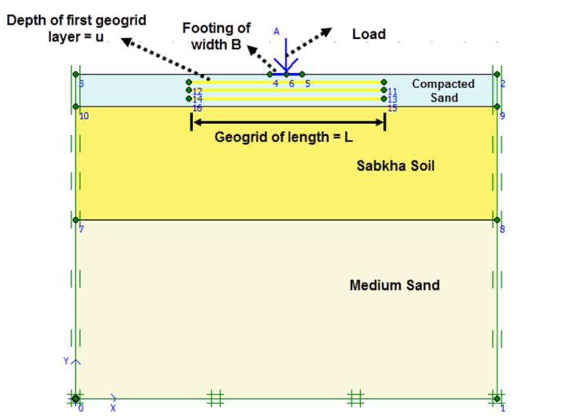


Fig. 4 Numerical model schematic in case of using Geogrids

The figures (5-10) demonstrate output of the program indicating mesh deformation and vertical displacements generated by footing load on unreinforced soil and reinforced with two types of reinforcement, respectively (fiber and geogrid).

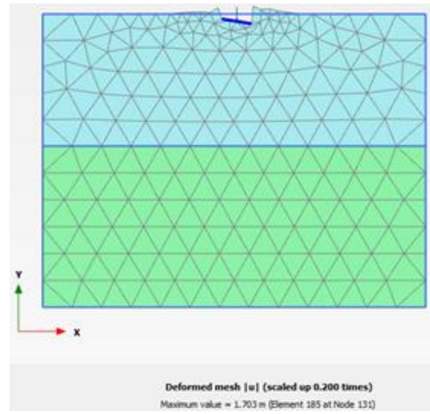


Fig. 5 Deformed mesh for unreinforced Sabkha

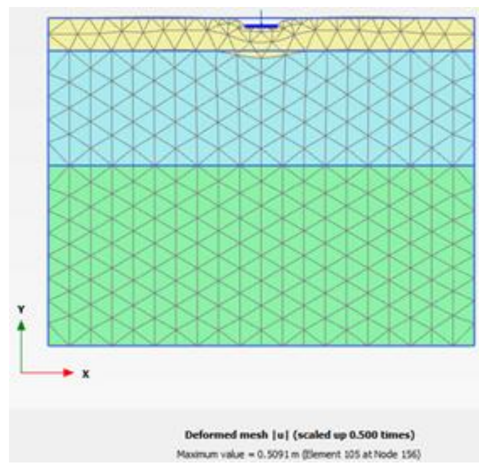


Fig. 6 Deformed mesh for fiber reinforced Sabkha

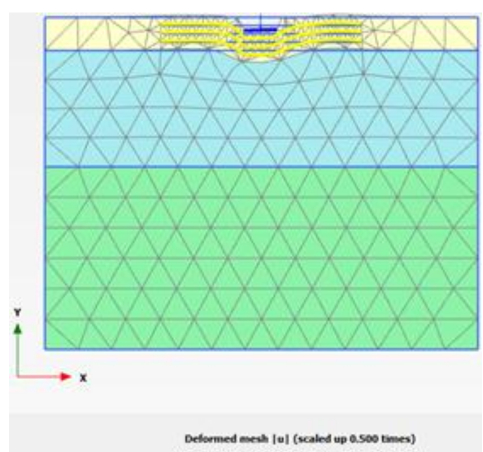


Fig. 7 Deformed mesh for Sabkha reinforced with Geogrids

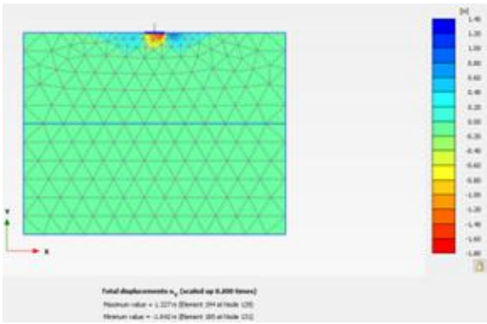


Fig. 8 Vertical displacements for unreinforced Sabkha

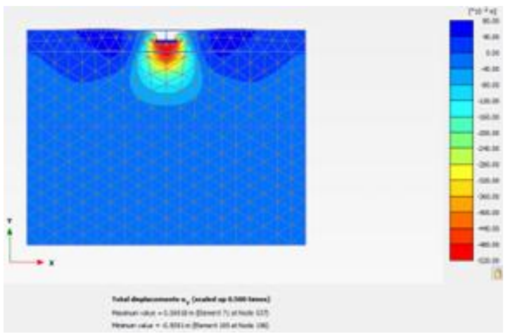


Fig. 9 Vertical displacements for Fiber reinforced Sabkha

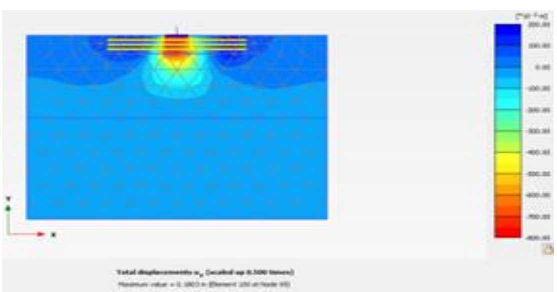


Fig. 10 Vertical Displacement for Sabkha reinforced with Geogrids

5 RESULTS AND DISCUSSION

A. Effect of Fiber reinforcement

The results relate footing pressure to settling. Figure 11 illustrates the connection between footing stress and settlement when the first form of reinforcement (fiber-reinforced sand) is applied to layers of varying thicknesses. Using randomly dispersed fibers raises the load carrying capacity of the footing by up to 353% when a fiber-reinforced layer with a thickness that is two times the width of the foundation is applied. The fiber-reinforced sand layer has higher load-bearing capacity than the unreinforced sabkha soil below it because of the increased stress distribution provided by the reinforcing fibers and the increased shear strength of the underlying sand. Settlement was also shown to be lower at the same stress levels.

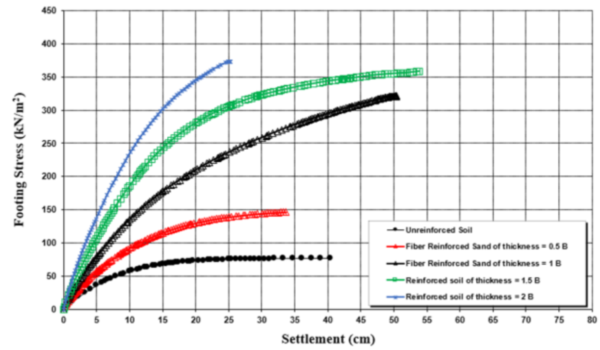


Fig. 11 Footing pressure vs settlement for Fiber reinforced Sabkha

B. Effect of Rubber reinforcement

For investigating the effect of using waste tire shreds-sand mixtures on the behavior of footing stress vs settlement curves were studied. As shown in figure 12 it was noted that using Sand-Rubber layer over sabkha soil improves the bearing capacity of foundation where ultimate bearing capacity grows by 220% when using a layer of sand-rubber mixture of thickness equivalent to double the breadth of the footing. Also, a significant reduction of settlement for all stress values.

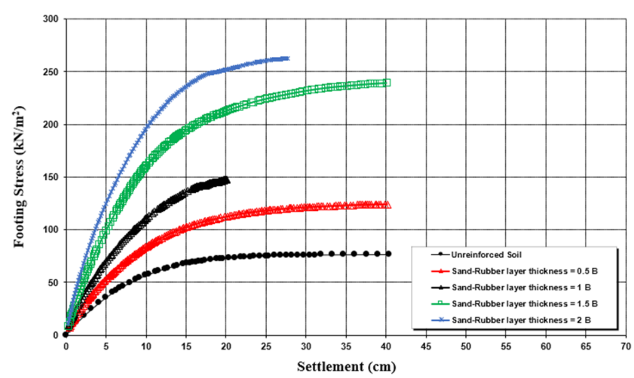


Fig. 12 Pressure vs settlement curves in case of Rubber reinforcement

C. Effect of Geogrids

Figure 13 illustrates the connection between footing stress and settling for the second reinforcing technique (Geogrids). The optimal geogrid length was determined to be L=6B, which is equivalent to six times the breadth of the footing. The impact of the number of geogrid layers was investigated. When three layers of geogrids with a length of L = 6B were used, the bearing capacity increased by 233%. The gain in bearing capacity is attributed to the utilization of geogrids, which reduce lateral soil motion and distribute loads over a larger surface.

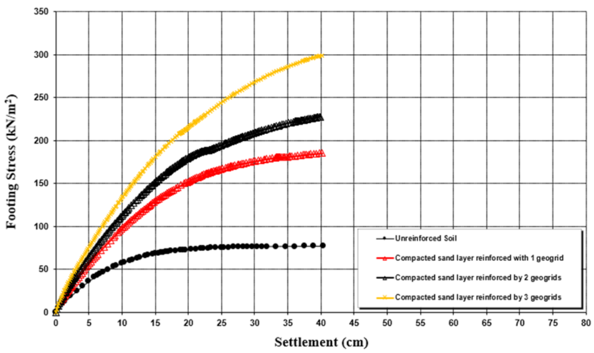
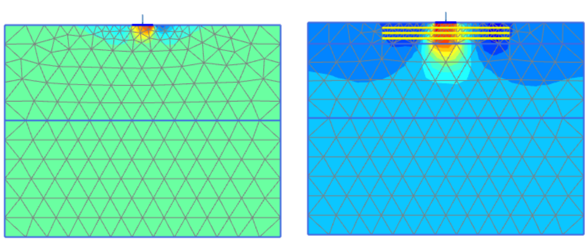


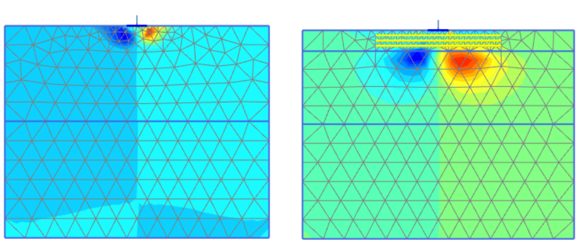
Fig. 13 Footing pressure vs settlement in case of Geogrids reinforcement

Fig. (14-15) present the maximum vertical and horizontal displacement below strip footing in case of unreinforced and geogrid reinforcement. It was observed that Geogrid reinforcement had limited effect on decreasing vertical settlement below strip footing but a notable effect of decreasing the horizontal displacement of soil below foundation (near the geogrid reinforcement) where the maximum displacement take place in lower weaker sabkha layer.



(a) **(b)**

Fig. 14 Vertical displacement in case of unreinforced and Geogrids reinforcement



(a) **(b)**

Fig. 15 Horizontal displacement in case of unreinforced and Geogrids reinforcement

D. Comparison of present work with previous results

Figure 16 presents a comparison of the percentage increase of ultimate bearing capacity values obtained from present work for different methods with the values obtained using chemical stabilization of sabkha soil by **[8]** and using Geotextiles by **[10].**

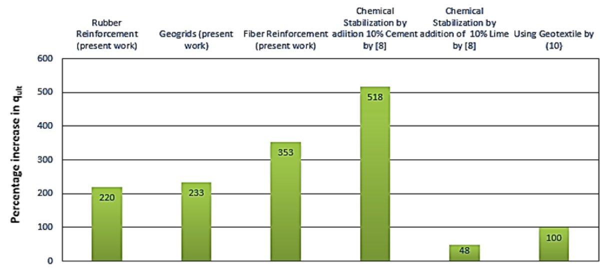


Fig. 16 Comparison of present work results with results obtained by **[8-10]**

From previous figure it is clear that chemical stabilization by mixing sabkha soil with 10% cement gives best results but it is not economical and practical like using a sand layer reinforced with Fibers, Rubber and Geogrids.

E. Bearing capacity failure mode

The shape of bearing capacity failure for strip footing on unreinforced sand is similar to general shear failure pattern obtained by (Terzaghi, 1943) **[27]** as shown in Figure 17 where entire failure mechanism lies within sabkha soil layer. Figures (17-20) presents total displacement shading obtained from Plaxis 3D output at failure for various cases.

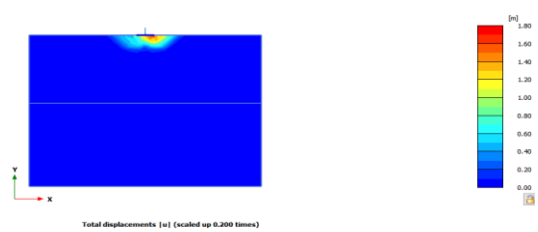


Fig. 17 Total displacement (u) shading for the case of unreinforced soil

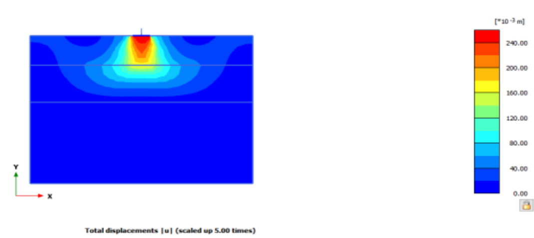


Fig. 18 Total displacement (u) shading for the case of using fiber reinforced sand layer

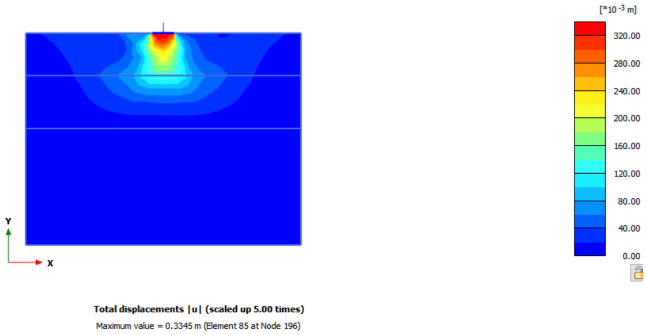


Fig. 19 Total displacement (u) shading for the case of using waste tire reinforced sand layer

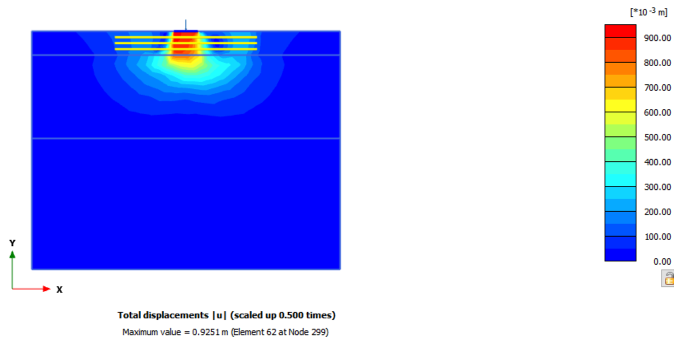


Fig. 20 Total displacement (u) shading for the case of using Geogrids

From figs. (18-19) it was observed that the bearing capacity failure mode is modified to punching shear failure in upper stronger reinforced layer and general shear failure in lower weaker sabkha layer. In case of using geogrids reinforced sand layer over sabkha layer it was observed that bearing capacity failure pattern is similar to what obtained by **[28].**

6 VERIFICATION OF THE NUMERICAL MODEL

First, a comparison was done to check numerical analysis findings. The ultimate bearing capacity of unreinforced and reinforced soil was calculated using the numerical analysis program Plaxis2D and conventional analytical techniques. Table 5 illustrates the comparison results.

The ultimate bearing capacity was obtained from numerical results from stress-settlement curves using tangent intersection method (Trautmann. C.H. and Kulhawy. F.H.,1988) **[29]**.

It was concluded from previous table that Plaxis2d software predicted the ultimate bearing capacity well where, a good agreement was observed between F.E.M. results and theoretical results specially in case of single layer soil such as the case of unreinforced soil. It was noted that in case of fiber and rubber reinforced soil which present the case of layered soil profile where stronger reinforced layer was underlined by a weaker Sabkha soil layer Plaxis gives lower bearing capacity values than obtained using theoretical methods which is similar to results obtained by **[30]**.

Also, a comparison is conducted between current finite element results with a previous physical experimental model on reinforced sand with geogrid performed by **[31].** The schematic of the prototype experimental model is shown in figure 21.

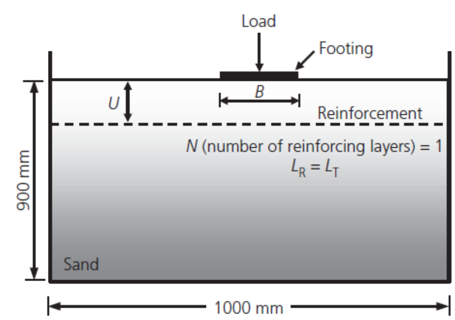


Fig. 21 Schematic diagram of experimental model by **[31]**

The dimensions of numerical model as shown in figure 22 is exactly the same like experimental model also, the material parameters of the soil, geogrid and strip footing all are the same as lab model to verify the accuracy of finite element software (PLAXIS2D).

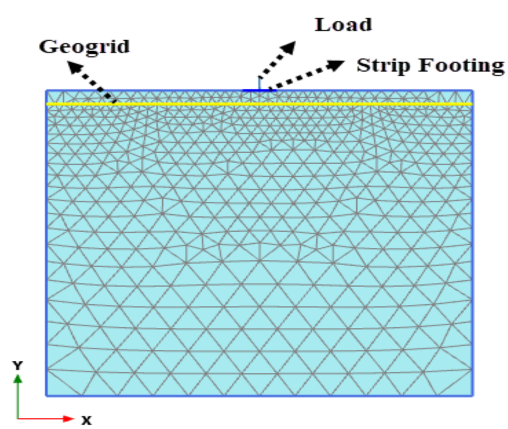


Fig. 22 Schematic diagram of the numerical model

Table 5. Comparison of Ultimate bearing capacity values q_u (kN/m^2) obtained by numerical analysis and analytical methods results

Case	Layer Thickness relative to footing width B	Terzaghi Method	Meyerhof Method	Hansen Method	Vesic Method	Numerical Results
Unreinforced soil	----------------	65	52	50	68	75
Fiber Reinforcement	**0.5B**	159	136	118	154	132
	1B	432	404	315	413	265
	1.5B	476	435	350	457	325
	2B	476	435	350	457	340
Rubber Reinforcement	**0.5B**	128	109	94	124	110
	1B	254	231	188	244	135
	1.5B	254	231	188	244	220
	2B	254	231	188	244	240

Table 6 presents a comparison the values of ultimate bearing capacity of strip footing of various sizes obtained from numerical analysis with and without geogrid reinforcement and previous physical model results by **[31].**

Table 6. Comparison of FE results with previous Exp. Results

Analysis type	Footing width (mm)			
	50	80	110	140
q_u (Exp.) kPa (Unreinforced)	56	71	94	112
q_u (FE) kPa (Unreinforced)	63	90	72	80
q_u (Exp.) kPa (Geogrid rft)	86	96	119	139
q_u (FE) kPa (Geogrid rft)	106	119	102	110

From previous figure it was observed that a good agreement is obtained for most cases between FE and Exp. Results.

7 CONCLUSIONS

The following is a summary of the findings drawn from the results:

- It was determined that the sand layer was accidentally reinforced with fibers, sand-rubber mixture significantly improved the bearing capacity of footing on sabkha soil. Using geogrid reinforcement also improved bearing capacity.
- When fiber reinforcement is used, the maximum increase in bearing capacity is up to 353%.
- The largest improvement in bearing capacity while utilizing a layer of sand-rubber combination was 220%.
- If geogrids are used the highest raise in bearing capacity reaches 233%.
- Geogrid reinforcement had limited effect on decreasing vertical settlement below strip footing but a significant effect of decreasing the horizontal displacement of soil below foundation
- It was found that for all approaches, a rise in bearing capacity value results in a fall in settlement for a given stress value.
- It is possible to draw the conclusion that using fiber-reinforced sand, a rubber-sand mixture, and geogrids as a reinforcement layer beneath a foundation sitting on sabkha soils is promising.

REFERENCES

[1] S.N. Abduljauwad, O. S .B. Al-Amoudi ,"Geotechnical behaviour of saline sabkha soils," Geotechnique, 45:425–445, 1995

[2] W. Akili, "On sabkha sands of Eastern Saudi Arabia," In: Proceedings Symposium on Geotechnical Problems in Saudi Arabia, Riyadh 2, pp. 775–797, 1981.

[3] W. Shehata, A. Saafin , Z. Harari, T. Bader ," Potential sabkha hazards in Saudi Arabia," In: 6th International IAEG Congress, Balkema, pp. 2003–2010, 1990.

[4] M. G. Abu Taleb,L. Egeli., "Some geotechnical problems in the Eastern Province of Saudi Arabia," In: Proceedings of

the Symposium on Geotechnical Problems in Saudi Arabia, pp. 799–811, 1981.

[5] Y. Juillie, D.E. Sherwood., "Improvement of sabkha of the Arabian Gulf Coast,". In: Proceedings of 8th European Conference Soil Mechanics Found. Engineering, pp. 781–788, 1983.

[6] W. Akili , N. Ahmad , "The sabkhas of Eastern Saudi Arabia-Geotechnical considerations,". In: Proceedings of the 1st Saudi Engineering Conference II. pp. 300–322, 1983.

[7] W. M. Shehata ,T. Bade , "Harari ZY, Principal Geological hazards along the Arabian Gulf coast. J King Abdulaziz Univ Earth Sci,", vol. 3, pp. 289–302, 1990.

[8] O. S.B. Al-Amoudi, "Characterization and chemical stabilization of Al-Qurayyah sabkha soil,". J Master Civ. Eng., vol. 14, pp. 478– 84, 2020, https://doi.org/10.1061/(ASCE)0899-1561(2002)14:6 (478)

[9] E. A. Yahia, .M. Aser, Y. A. Mohamed, "The Performance of Strip Footing Resting on Geogrid- Reinforced Dune Sand," Geo-China (ASCE) GSP 261,2016.

[10] S.N. Abduljauwad , F. Bayomy , Al-Shaikh AKM, O. Al-Amoudi , "Influence of geotextiles on performance of saline sebkha soils," J Geotech Eng., vol. 120, pp. 1939–1960, 1994

[11] Z. U. Siddiqi, , "Effects Of Geotextiles On The Load-Carrying Capacity Of Pavements On Sabkha,". MS Dissertation, KFUPM. 2000.

[12] S. Aiban, H. Al-Ahmadi, I. Asi, Z. Siddique, and O. Al-Amoudi., "Effect Of Geotextile And Cement On The Performance of Sabkha Subgrade," Building and Environment. Vol. 41, no. 6, pp. 807-820, 2005.

[13] H. O. Abbas, "Improvement of Sabkha Soil by Using Geomesh and Addition of Polycoat," Eng. & Tech. Journal, Vol.30, No.4, pp. 568-576, 2012.

[14] N. Benmebarek, B. Fouad and B. Sadok, "Numerical analysis of embankment reinforced by geosynthetics on sabkha soil,". 3rd International Conference on New Developments in Soil Mechanics and Geotechnical Engineering, Near East University, Nicosia, North Cyprus, pp. 117-123, 28-30 June 2012.

[15] D. AL-JEZNAWI1, A. A. AL-azzawiI, "The Behavior of Strip Footing Resting on Soil Strengthened with Geogrid," Civil and Environmental Engineering, Vol. 17, Issue 2, pp. 597-609, 2021, DOI: 10.2478/cee-2021-0060.

[16] J. Chen, G. XiaopengI, S. RUI, R Sathiyamoorthy , J. Song, X. Jianfeening, "Physical and numerical modelling of strip footing on geogrid reinforced transparent Sand. Geotextiles and Geomembranes," Vol. 49, Issue. 2, pp. 399-412, 2021.

[17] M. Diakoumi, K. Stone, D. Roddy, "Effect of fiber reinforcement on the bearing capacity of a surface strip foundation,". In J. Laue, & T. Bansal (Eds.), Proceedings of the 4th European Conference on Physical Modelling in Geotechnics, Luleå University of Technology, pp.227-232., 2021

[18] M. Benziane ,N. Della, S. Denine ,S., Sert, S. Nouri,"Effect of randomly distributed polypropylene fiber reinforcement on the shear behavior of sandy soil," Studia Geotechnica et Mechanica, vol. 41, no.3, pp. 151–159, 2019.

[19] N. Nader Hataf , and M.M. Rahimi, "Experimental investigation of bearing capacity of sand reinforced with randomly distributed tire shreds," Construction and Building Materials, pp. 910-916, 2006

[20] A. M. Alnuaim and M. H. El Naggar, "Performance of Shallow Foundation on Sabkha Soil,". Proc. 3rd Specialty Conference on Material Engineering & Applied Mechanics, Montreal, Quebec, May 29 to June 1, 2013.

[21] M. Joon-Shik , J. Hyuk Sang ,L. Sungjune and S.T. Kang, "Ground Improvement Using Dynamic Compaction in Sabkha Deposit,". Applied Sciences journal. Vol. 9, no.12, pp. 2506, doi:10.3390/app9122506, 2019.

[22] A. Hassan. Abbas, "Numerical Model of Stone Column in Sabkha Soil,". International Research Journal of Innovations in Engineering and Technology (IRJIET), Vol. 3, Issue 9, pp. 8-11, September 2019.

[23] K. Abd-El Moneim, "Sand Reinforced with Shredded Waste Tire,". M. Sc. Thesis, Department of Structural Engineering, Tanta University, Egypt, 2008.

[24] BRINKGREVE, R. B. J.: "PLAXIS 2D Manual," Delft, 2020.

[25] R.B.J. Brinkgreve, E. Engin, and H.K., Engin, "Validation of empirical formulas to derive model parameters for sands," Knowledge base publications of plaxis, Plaxis B. V., Delft, Netherlands, 2010.

[26] K. M. Bahloul, "Contribution to the study of foundation on soft clay in the north of nile delta" A THESIS submitted for the award of a Ph. D. Degree, Department of Structural Engineering, Technical University of Civil Engineering of Bucharest (UTCB), Romania, 2005.

[27] G. G. Meyerhof,, "The ultimate bearing capacity of foundations," Geotechnique, vol. 2, no.4, pp. 301-332, 1951

[28] J. Binquet, K.L. Lee, "Bearing capacity analysis of reinforced earth slabs," Journal of Geotechnical Engineering Division, ASCE, vol.101, no. 12, pp. 57-76, 1975.

[29] C.H. Trautmann, F. H. Kulhawy, "Uplift Load - Displacement Behavior of Spread Foundations," Journal of Geotechnical Engineering, ASCE, vol 114, no.2, pp. 168 – 183, 1988.

[30] H. Belachew, "Evaluating Bearing Capacity of Layered Soils Using Finite Element Analysis Software,". M. Sc. Thesis, ADDIS ABABA, INSTITUTE OF TECHNOLOGY, DEPARTMENT OF CIVIL ENGINEERING, 2017

[31] A.M. Nasr, W.R. Azzam, "Behaviour of eccentrically loaded strip footings resting on sand," International Journal of Physical Modelling in Geotechnics. Volume 17 Issue 3, pp. 177-194, September 2017.